

CONS/4396-3
NASA CR-159436

(NASA-CR-159436) AUTOMOTIVE STIRLING ENGINE
DEVELOPMENT PROGRAM Quarterly Technical
Progress Report, Apr. 1978 - Jun 1978 (Ford
Motor Co.) 96 p HC A05/MF A01 CSCL 13F

N79-11406

Unclas
G3/37 37162

AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM

Quarterly Technical Progress Report
April 1978 - June 1978

Ford Motor Company
Dearborn, Michigan 48121

Prepared for the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Cleveland, Ohio 44135

Contract EC-77-C-02-4396



As a part of the
DEPARTMENT OF ENERGY
Division of Transportation Energy Conservation
Heat Engine Highway Vehicle Systems Program

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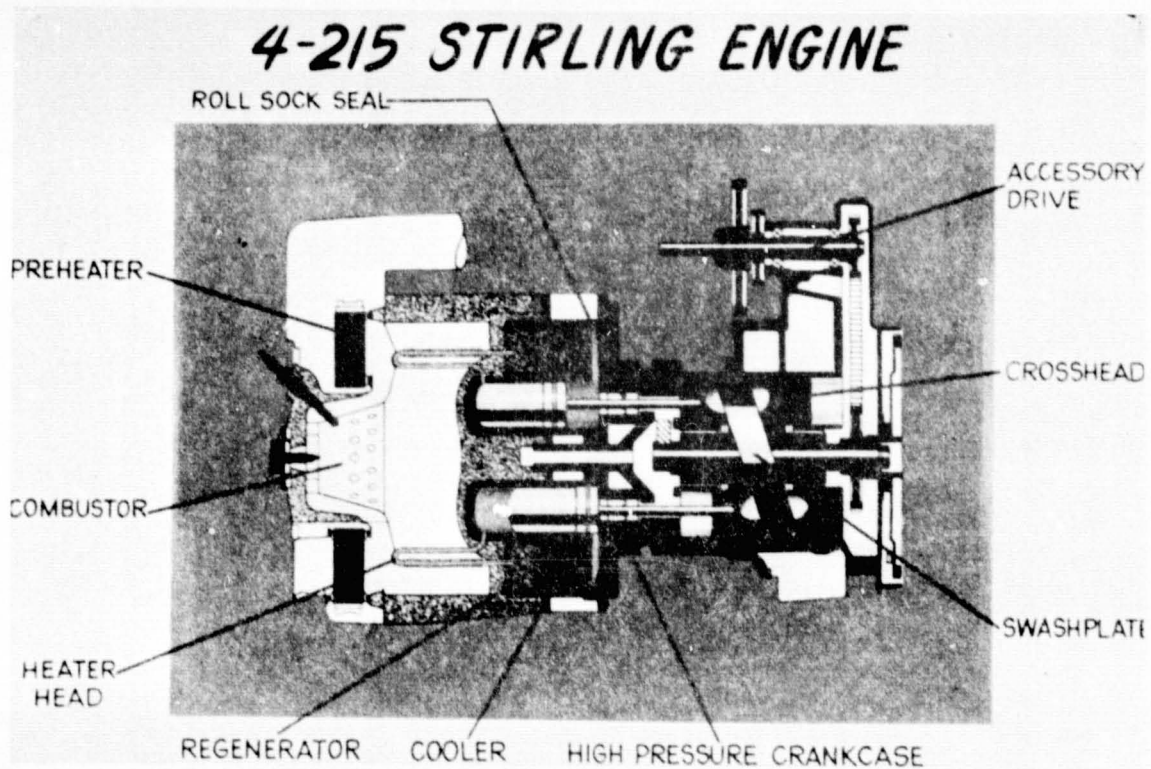
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FRONTISPIECE



SECTION 1

EXECUTIVE SUMMARY AND INTRODUCTION

I. EXECUTIVE SUMMARY

This report covers the third quarter (April-June, 1978) effort of the Ford/DOE Automotive Stirling Engine Development Program, specifically Task I of that effort which is Fuel Economy Assessment. At the end of the previous quarter (March 31, 1978) the total fourth generation fuel economy projection was 23.7 MPG (gasoline) with a confidence level of 40%. At the end of this quarter (June 30, 1978) the total fourth generation fuel economy projection was 26.12 MPG (gasoline) with a confidence level of 44%. This represents an improvement of 66.4% over the baseline M-H fuel economy of 15.7 MPG. The confidence level for the original 20.6 MPG goal has been increased from 53% to 57%.

Engine 3X17 has now accumulated a total of 213 hours of variable speed running.

The following is a summary of the individual sub-tasks of Task I. The sub-tasks are grouped into two categories: Category 1 consists of those sub-tasks which are directly related to fuel economy and Category 2 consists of those sub-tasks which are not directly related to fuel economy but are an integral part of the Task I effort.

CATEGORY 1

Mapping and Optimization - Sub-task 01

Mapping of vehicle simulation points 1, 4, 5, and 6 was completed in dynamometer cell 10. Simulation point 9 is presently being mapped.

Preparation of dynamometer cell 1 has been completed and the emission equipment has been calibrated and tested.

The assessed maximum fuel economy improvement opportunity of Mapping and Optimization, sub-task 01, was reduced during this quarter from 0.26 MPG to 0.25 MPG (gasoline), due to a theoretical analysis performed on the sub-sub-task "Temperature Scheduling."

Burner System - Sub-task 02

Assembly of the Engine Simulator Test Rig was completed. The rig was initially checked out using the baseline burner system hardware and the Excelllo fuel nozzle.

The baseline burner system with the Philips pintle and Excelllo fuel nozzles was tested on the Atmospheric Burner Test Rig.

The video tape recorder system, which will be used to monitor and create visual records of testing on the Atmospheric Burner Test Rig, was received.

Burner System - Sub-task 02 (Continued)

A modified IJS combustor, having a different arrangement of impingement jet holes, has been fabricated.

The assessed maximum fuel economy improvement opportunity of Burner System, sub-task 02, remained unchanged during this quarter at 0.20 MPG (gasoline).

Preheater Development - Sub-task 03

Work on the engine driven preheater was completed.

The preheater drive motor, with the overriding clutch, is ready for test on the dynamometer engine.

The redesigned preheater assembly is ready for test on the dynamometer engine.

The thin wall preheater cores are ready for testing on the Preheater Test Rig.

The assessed maximum fuel economy improvement opportunity of Preheater Development, sub-task 03, remained unchanged during this quarter at 0.18 MPG (gasoline).

Engine Drive Study - Sub-task 04

A preliminary stress analysis was performed on the 4-215 Stirling engine. This analysis indicated that the swashplate could be reduced in thickness by approximately 0.9 in. (2.29 cm) and still retain adequate strength.

The M-H fuel economy projection for the dual crankshaft engine has been increased by 0.05 MPG to account for the lack of accessory drive losses in this engine (i.e., there is no drive chain or accessory drive shaft). The M-H fuel economy projection for the dual crankshaft engine is now 15.9 MPG (gasoline) compared to 16.17 MPG projected for the swashplate drive engine.

The Air Atomizer Pump Test Rig was completed.

The Piston Ring Test Rig was modified to provide better oscilloscope readings.

A scarf-type piston ring joint was proven to have poor sealing characteristics; therefore, a step joint will be used for future tests.

The assessed maximum fuel economy improvement opportunity of Engine Drive Study, sub-task 04, was increased during this quarter from 0.74 MPG to 1.64 MPG (gasoline). This increase is the result of the improved crosshead design.

External Heat and Blower System - Sub-task 05

Layout and detailing on the new blower design has been completed. The drawings of the housing and impeller have been checked and an order was placed for three sets of housing castings, three impeller assemblies, three shafts, and three pulleys.

The assessed maximum fuel economy improvement contribution of External Heat and Blower System, sub-task 05, remained unchanged during this quarter at 0.46 MPG (gasoline).

Power Control - Sub-task 08

Testing of the linear power control valve indicated leakage across the transfer valve portion. Because the transfer valve function is not an essential operation, it has been sealed off and the function will be performed externally with an existing valve.

The 4-215 linear power control module was tested. A penalty of .02 MPG was noted.

The computer program initially written to determine the mechanical losses of the hydrogen compressor has been expanded to enable the additional calculation of pumping work. The program has the capability of determining sliding seal friction and the resultant shaft power.

The Compressor Test Rig experienced scuffing in both cylinder walls after 3 hours of initial steady running. The cylinder walls were rebored, the plunger-posts were realigned, and testing was resumed.

The initial analytical study of compressor losses and their impact on fuel economy has been completed.

The assessed maximum fuel economy improvement opportunity of Power Control, sub-task 08, was decreased in May, 1978 from 1.44 MPG to 1.39 MPG (gasoline). This decrease was due to a reassessment of the "Sealed Dome" sub-sub-task. It was decided that the fuel economy improvement of this sub-sub-task would be reduced from 0.05 MPG to 0.00 MPG. However, in June, 1978 the fuel economy opportunity of Power Control was increased from 1.39 MPG to 1.40 MPG (gasoline) due to a better hydrogen compressor loss analysis.

Air/Fuel Control - Sub-task 09

Technical representatives from Ultra Electronics spent two weeks investigating a noise problem in the PAC 500 control. The problem was located and corrected.

The air/fuel control system in dynamometer cell 10 was removed due to an apparent shift in calibration. This system was replaced with one from the fuel flow lab.

The wiring of the Engine Simulator Test Rig in dynamometer cell 3 was completed and the air throttle and EGR valve positioning systems have been installed and checked out.

The test and evaluation of the United Stirling dual pump metering system has been completed. The varying frictional forces presented by the dual pump at low speeds, in the 0.4 grams/sec. fuel flow range, make it very difficult to provide a motor drive capable of holding a constant low RPM speed.

The test and evaluation of a turbine air flow meter from Autotronics Corporation has been completed. The meter was found unacceptable for application on the Stirling engine.

The assessed maximum fuel economy improvement opportunity of Air/Fuel Control, sub-task 09, remained unchanged during the quarter at 0.25 MPG (gasoline).

Cycle Analysis - Sub-task 10

The projected fuel economy improvement opportunity for sub-sub-task "Heater Tube Heat Flux" has been reduced from 0.16 MPG to 0.00 MPG. This reduction is due to the fact that heater tube heat flux is primarily dependent on full-load power, engine length, and engine diameter.

An optimization was completed with the cold-start fuel penalty incorporated into the optimized function. Analysis revealed that, using the same constraints and requirements of the fourth generation fuel economy engine on the 4-215 Stirling engine, there is no fuel economy improvement available.

Due to some problems in the optimization procedure (not the algorithm that calculates the Stirling cycle), previous optimizations were not searching properly for the maximum fuel economy. With these problems corrected, the results from the optimized engine indicate an increase in the incremental fuel economy improvement of 1.40 MPG (gasoline).

The assessed maximum fuel economy improvement opportunity of Cycle Analysis, sub-task 10, was increased during this quarter from 2.38 MPG to 3.60 MPG (gasoline).

Other Fuel Economy Improvements - Sub-task 14

Sub-sub-task "Methods to Reduce Conduction Losses (Insulation)" has been added to this sub-task and the associated estimate for improvement in fuel economy of the fourth generation engine is 0.5 MPG (gasoline).

The assessed maximum fuel economy improvement contribution of Other Fuel Economy Improvements, sub-task 14, was increased during this quarter from 2.02 MPG to 2.52 MPG (gasoline).

Cooling System - Sub-task 15

The transparent plastic model which simulates the Stirling engine water jacket in the vicinity of the piston rod seals was fabricated, inspected, checked for leakage, and delivered.

The assessed maximum fuel economy improvement opportunity of Cooling System Analysis, sub-task 15, remained unchanged during this quarter at 0.06 MPG (gasoline).

Fuel Economy Analysis - Sub-task 06

The TOFEP computer program was modified to provide better part-throttle engine conditions via different shift points. The input data for this program was also modified to provide corresponding absolute fuel economy projections for the baseline vehicle.

The PB1111 computer program was used to determine what changes were required to the torque levels of the TDEM247C engine map to achieve a 0-60 MPH acceleration time equal to that of the 351M IC engine-powered baseline vehicle (13.3 sec).

Fuel Economy Analysis - Sub-task 06 (Continued)

The Master Fuel Economy Assessment Chart was updated to include "Confidence Weighted Opportunities," and also list maximum and minimum fuel economy opportunities. Also, two baseline fuel economy projection numbers now appear in the "Vehicle Projection" column.

CATEGORY 2

Engine Durability Upgrading - Sub-task 07

Pressure drops were recorded on ten regenerators which were received from N. V. Philips. The data from the testing of these regenerators was transmitted to N. V. Philips for a theoretical analysis.

The Rollsock Seal Test Rig set-up was completed and testing was initiated on seal assemblies which were modified to include a check valve seal between the pumping ring and the rollsock.

Two sets of F-1 seals were run on the Compressor Drive Test Rig. Each set allowed large amounts of oil into the gas space in a relatively short time.

Testing of a set of F-4 seal cartridges began on the Compressor Drive Test Rig. The first set of cartridges completed approximately 65 hours of testing at 1000 RPM and 800 psi mean pressure with no indication of oil in the gas space.

The Swashplate Drive Test Rig modifications were completed and the reworked parts were received. Assembly of the rig is now complete.

A second set of F-4 seals completed 100 hours of testing on the Compressor Drive Test Rig at 1000 RPM and 800 psi mean pressure. One seal assembly allowed no oil past the scraper either into the test cylinder or the seal cartridge. The other seal had a light film of oil inside the seal cartridge and possibly the test cylinder.

A third pair of F-4 seals also completed 100 hours of testing on the Compressor Drive Test Rig at 1000 RPM and 1000 psi mean pressure. Both seal assemblies were equipped with a Parker SCL seal. One of the SCL seals failed after 50 hours of testing and was replaced with a solid ring made of Rulon LD. When the test was completed, the cylinder with the solid ring had no oil in either the cartridge or the cylinder; however, the Rulon ring was badly worn and had extruded into the clearance gap.

Testing of the fourth set of F-4 seals has been initiated on the Compressor Drive Test Rig.

An analysis was performed to determine the order of magnitude of the temperature gradient which exists along the piston rod, since a large gradient could possibly result in less effective sealing. Approximate modeling of the spatial heat generation, conduction, and rejection indicates that the expected temperature gradient is not acceptable.

Reference Engine - Sub-task 13

A more detailed version of a double crank engine is presently being laid out. Engine auxiliary mountings will be investigated in an effort to have more realistic engine installation studies.

Prepared by:

E. W. Kitzner

E. W. Kitzner, Manager
Alternate Engines Research Dept.
Ford Motor Company
Technical Manager, Stirling
Engine Program

Approved by:

J. D. Tullena for

R. C. Ronzi, Director
Engines & Emissions Research Office
Ford Motor Company
Program Manager, Stirling Engine Program

II. INTRODUCTION

This report is the third in a series of quarterly reports designed to detail the progress of the Ford/DOE Automotive Stirling Engine Development Program. This report contains no information pertaining to background or present contract. If that information is required, refer to the first Quarterly Technical Progress Report (CONS/4396-1-NASA CR-135331). This program is jointly funded by Ford Motor Company and the United States Department of Energy (DOE) under contract number EC-77-C-02-4396 which was effective September 19, 1977. The Department of Energy has delegated project management responsibility for this contract to the NASA-Lewis Research Center in Cleveland, Ohio.

The Automotive Stirling Engine Development Program is directed toward establishing the technological and developmental base that would enable a decision on whether an engineering program should be directed at Stirling engine production. Such engines are believed to provide an attractive alternative for meeting national needs related to fuel consumption and environmental protection. For example, the fuel economy of a Stirling powered automobile is estimated to be nominally 30% greater than that of a 1977 spark ignition engine powered automobile of equivalent size, weight, and performance. It is estimated that the Stirling engine powered automobile will also meet the 1976 standards set forth in the Clean Air Amendments of 1970.

The program is divided into twelve overlapping Tasks. Four of these Tasks are directed toward the iterative development of the Stirling Engine System via a series of engine "generations."

Task I covers the first year's effort of the program. The objective of this Task is to perform certain analyses and component development work for the purpose of determining whether the fuel economy objective established for the fourth generation Stirling engine (30% improvement) can be achieved. To accomplish this objective, durability upgrading of the current Stirling engine is required.

Specifically, Task I is directed toward achieving, with a high degree of confidence, the May 12, 1977 ERDA proposal estimate of 20.6 MPG (gasoline) for a 4500 lb. IWC Stirling engine powered passenger car. At this time, the confidence level for this projection, using fourth generation technology, is 26.1 MPG with a confidence level of 44%.

SECTION 2

TASK I, FUEL ECONOMY ANALYSIS

I. GENERAL

Task I of the Automotive Stirling Engine Development Program has been divided into two categories. Category 1 consists of those sub-tasks that are directly related to fuel economy. Category 2 consists of sub-task 7, Engine Durability Upgrading; sub-task 11, Responsive Support; sub-task 12, Contract Support; and sub-task 13, Reference Engine. These sub-tasks are not directly related to fuel economy evaluation but are an integral part of the Task I effort. Each of the fifteen sub-tasks will be reported on individually.

II. REPORT FORMAT

Each sub-task consists of several separate but related operations which are listed as sub-sub-tasks. The report for each sub-task is as follows:

- a. A timing chart of the sub-task which contains the following information (see Example Timing Chart, figure II-1).
 1. A horizontal bar(s) which appears to the right of the respective sub-sub-task.
 2. Target deadlines which are represented by circles and located along the bar. The dates of these deadlines are shown by the calendrical scale which appears at the top of each chart. At the end of each quarter, the bars are shaded according to the amount of progress made during that quarter.
 3. At strategic locations along these bars circles appear which contain one of the letters E, A, C, or D. The letters represent the following:
 - a) E = Estimate. This estimate represents the fuel economy improvement estimate which existed for that particular sub-sub-task at the beginning of the contract (September 19, 1977).
 - b) A = Theoretical Analysis. A theoretical analysis will be assigned to selected sub-sub-tasks during the Task I effort.
 - c) C = Component Test. Certain sub-sub-tasks interpret into actual component parts of the Stirling engine system (SES). In this case, after a theoretical analysis is performed and results indicate a measurable improvement in fuel economy, this component will be bench or rig tested. If these results reinforce the results of the theoretical analysis, then the component will eventually be tested on the dynamometer.
 - d) D = Dynamometer Engine Test. This is the last phase of component testing in regard to fuel economy improvement. At this point, the component will be ready for installation on the reference engine.

These letters are used in conjunction with the individual fuel economy assessment charts which appear at the bottom of each timing chart. The individual fuel economy assessment charts are explained in this section.

4. A box(s) may also appear along the horizontal bar(s) which contains a double digit number. The number represents the number of the sub-task from which data is being received or to which data is being sent (depending on the direction of the arrow). This interface also falls within the time frame depicted by the calendrical scale.
- b. A Fuel Economy Assessment (MPG) chart, where applicable, which has been extracted from the master Fuel Economy Assessment chart (sub-task 06, Fuel Economy Analysis). The individual charts show the Fuel Economy Assessment (MPG) of the sub-sub-tasks as follows:
1. The original estimate which was included in the ERDA Proposal of May 12, 1977.
 2. The estimate as of September 19, 1977 (contract start date). This estimate underwent reassessment and differs from the original estimate proposed to ERDA on May 12, 1977.
 3. The estimate of each individual sub-sub-task after Theoretical Analysis, Component, and Dynamometer Testing.
- A shaded area in one or more of the columns adjacent to the sub-sub-task indicates that the sub-sub-task is not scheduled for the respective test at this time.
4. The column to the right indicates the projected Fuel Economy Assessment (MPG) of a 4-215 sized fourth generation Stirling engine in the baseline vehicle. The individual charts do not include the confidence level of these projections. Confidence level information is located on the master Fuel Economy Assessment chart which is attached to sub-task 06, Fuel Economy Analysis.
- c. A written report detailing the progress of each sub-sub-task. This page will contain, when applicable, a concise description of the work performed, problems encountered, the "fix" to the problems, and the work planned for the next reporting period. In the event that a particular item requires additional explanation, an attachment(s) will be referenced on this page and included in the report.

The following reports will cover the progress of each individual sub-task. Instead of listing the sub-tasks in numeric order (01 through 15), the sub-tasks were placed into two categories as follows.

Category 1

- . Mapping and Optimization - sub-task 01
- . Burner System - sub-task 02
- . Preheater Development - sub-task 03
- . Engine Drive Study - sub-task 04
- . External Heat and Blower System - sub-task 05
- . Power Control - sub-task 08
- . Air/Fuel Control - sub-task 09
- . Cycle Analysis - sub-task 10
- . Other Fuel Economy Improvements - sub-task 14
- . Cooling System Analysis - sub-task 15
- . Fuel Economy Analysis - sub-task 06

Category 1 consists of those sub-tasks which are directly related to fuel economy. Fuel Economy Analysis - sub-task 06, is placed at the end of this category because a portion of this sub-task is dedicated to coordinating all the fuel economy improvement contributions from the other sub-tasks in Category 1 and listing them on the master Fuel Economy Assessment chart located in sub-task 06. Concurrent with coordinating the fuel economy improvement contributions, a confidence level for these fuel economy improvement numbers is also assigned.

Category 2

- . Engine Durability Upgrading - sub-task 07
- . Responsive Support - sub-task 11
- . Contract Support - sub-task 12
- . Reference Engine - sub-task 13

Category 2 consists of those sub-tasks not directly related to fuel economy but are nevertheless an integral part of the Task I effort.

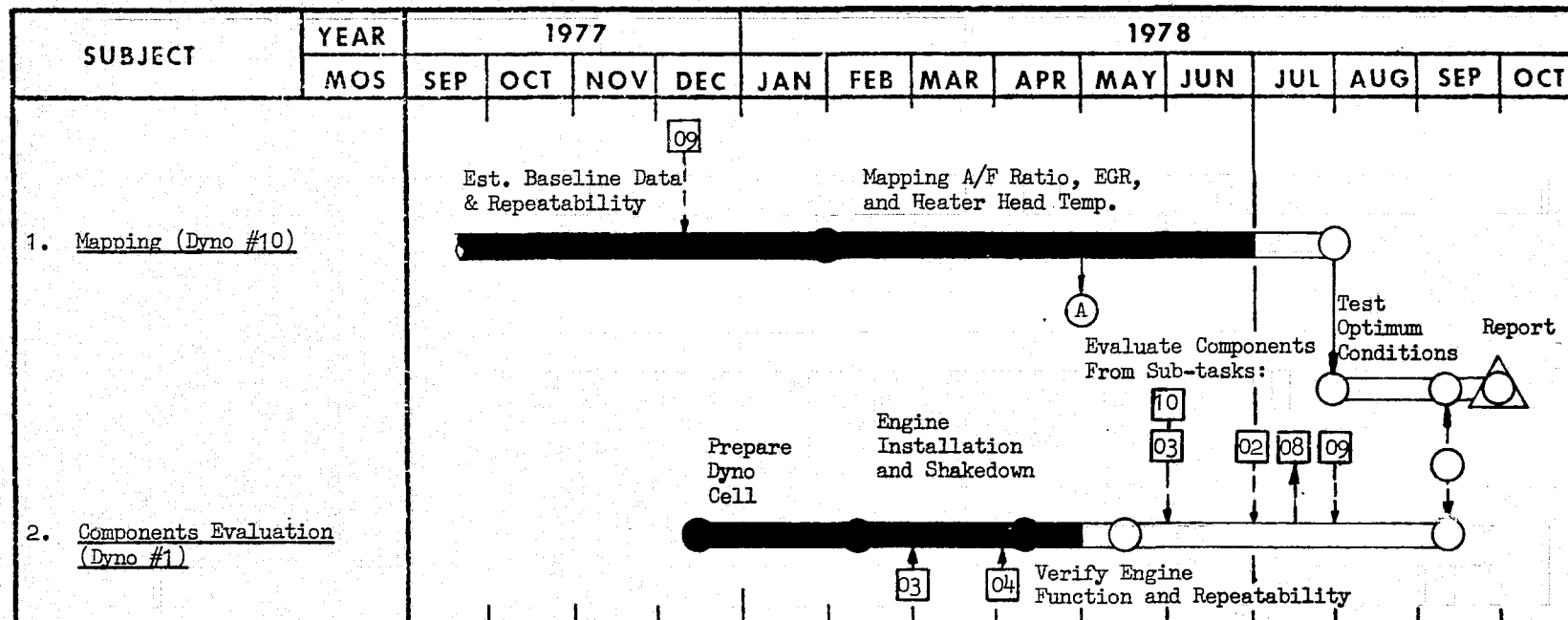
III. Individual Sub-task Progress

The following reports detail the progress of each individual sub-task.



FIGURE II-1

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FUEL ECONOMY ASSESSMENT (MPG)							
Sub-Task No.	Sub-Task Description	ERDA Proposal Estimate (1)	(E) Estimate	(A) Theoretical Analysis	(C) Component Test	(D) Dyno. Engine Test	Vehicle Projection
01	MAPPING & OPTIMIZATION (ERVIN)						.25
	.Reduced EGR requirements	.04	.04				
	.Reduced exhaust back-pressure	.03					
	.Minimize air flow reqmts.	.04	.04				
	.Temperature scheduling	.27	.45	.14/20%			

MAPPING AND OPTIMIZATION - SUB-TASK 01

Mapping of vehicle simulation points 1, 4, 5, and 6 was completed on engine 3X17 in dynamometer cell 10. Simulation point 9 is presently being mapped. Data from points 1, 4, 5, and 6 indicates that mapping and optimization will project a maximum fuel economy improvement opportunity of 0.13 MPG (gasoline) for optimum EGR and air/fuel ratio settings and 0.32 MPG (gasoline) for optimum temperature setting. A Test Summary (PTS-097) describing the mapping results of these points was written and submitted to NASA. A synopsis of this Test Summary is included (refer to Attachment 1).

Preparation of dynamometer cell 1 has been completed and the emission equipment has been calibrated and tested. Component testing, using engine 1X18, should begin early in July.

FUEL ECONOMY ASSESSMENT

The assessed maximum fuel economy improvement contribution of Mapping and Optimization, sub-task 01, was reduced during this quarter from 0.26 MPG to 0.25 MPG (gasoline). This decrease was the result of a theoretical analysis performed on the sub-sub-task "Temperature Scheduling" (refer to the Master Fuel Economy Assessment Chart, Attachment 10).

SYNOPSIS OF TEST SUMMARY PTS-097

"Mapping and Optimization Testing of the 4-215 Stirling Engine"**Objective:**

To determine the effect of air/fuel ratio, EGR, and hydrogen temperature on M-H fuel economy and exhaust emissions.

Summary:

- Due to limited durability of earlier engine builds, it was decided that the engine would be tested at four vehicle simulation points (No. 1, 4, 5, and 6). These results would be used along with theoretical projections to determine the total effect of optimizing air/fuel ratio, EGR, and temperature for the total (10) vehicle simulation points.
- Testing will continue with mapping and optimization of simulation points No. 7, 8, 9, and 10. If the engine remains operational, the remaining two points, No. 2 and 3, will be tested.
- Summaries of the test data for the four simulation points are given in Tables 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10.

Results:

- Data from tests at the first four VS points indicates that an improvement of no more than 1% in fuel economy can be expected for an optimum EGR and air/fuel setting, when compared with the baseline settings. If this trend holds true for all 10 VS points, the maximum fuel economy improvement over the CVS cycle will be about .13 MPG.
- The improvement in fuel consumption due to temperature scheduling is expected to be less than 2.5% when fuel consumption at optimum heater temperature is compared with the baseline setting of about 720°C. The fuel economy improvement over the CVS cycle is expected to be no more than .32 MPG. The effects of transient conditions, which is expected to be detrimental, are not included in this analysis.
- Fuel consumption at various hydrogen temperatures from 680°C to 800°C was measured with the exhaust emissions held at an approximately constant level. The results are shown graphically in Figure 1. Total variation in fuel flows in this temperature range was approximately 5% for each simulation point. The minimum fuel flow for each point, however, occurred at different temperatures. These are:

<u>Simulation Point No.</u>	<u>Min. Fuel Flow Temp. (°C)</u>
1 (600 RPM, 5.4 kg-m)	680
4 (1000 RPM, 6.9 kg-m)	730
5 (1100 RPM, 11.1 kg-m)	764
6 (1300 RPM, 15.9 kg-m)	780

Because of a rapid drop in hydrogen temperature during heavy acceleration, 700°C has been established as a minimum controlled temperature.

- Fuel consumption and exhaust emission (HC-CO-NOx) was measured for various air/fuel ratios and EGR levels at a constant hydrogen temperature for the four simulation points.

All test points, except No. 4, were run more than once to verify or check the results of the original run.

Fuel flow, except at simulation point No. 1, varied directly with EGR and air/fuel ratio. The fuel flow within the range of air/fuel ratios and EGR loads tested varied about 3% at point No. 1 to 8% at point 6. When emission constraints (maximum CO and maximum NOx values) are considered, the total fuel flow variation is 1% to 5% for points 1 and 6.

- Carbon monoxide varied indirectly with air/fuel ratio, but EGR had very little effect on CO emissions. The relationships of CO emissions to air/fuel ratio were:

VS Point	Fuel (g/s)	CO Concentration in 4-215 Stirling Exhaust (PPM)			
		Equivalence Ratio (A/F Ratio)			
		1.3 (19.0)	1.4 (20.5)	1.5 (22.0)	1.6 (23.4)
1	0.6	-	1380	660	360
4	1.0	1400	700	400	320
5	1.4	1000	560	380	290
6	2.0	600	400	320	280

- Oxides of nitrogen varied primarily with EGR, but also with air/fuel ratio. Both higher EGR yields and lower A/F ratio yields lower NOx. Changes in EGR at values less than 110% had a great effect on NOx, i.e., a change in EGR of 10 percentage units caused a change in NOx of about 5-10 PPM. EGR values greater than 110% had a lesser effect on NOx, i.e., a change in EGR of 10 percentage units caused a change in NOx of about 2-5 PPM.

Small changes in air/fuel ratio did not have significant effect on NOx concentration, however, a decrease of 30% excess air (A/F ratio) caused about a 10-20 PPM decrease in NOx.

Hydrogen (heater) temperature also affected NOx concentrations in the exhaust. As indicated from the temperature schedule data (Tables 3, 5, 7, and 10), a 10°C change in hydrogen temperature required a 2-5 percentage unit change in EGR to maintain a constant NOx level.

- Hydrocarbon concentrations were extremely small (1-10 PPM) at all conditions and were ignored in mapping and optimization evaluation.

TABLE 1
MAPPING & OPTIMIZATION SUMMARY

Simulation Point No. I
(600 RPM, 5.4 kg-m Torque)

Run No.	Equiv. Ratio (X)	EGR (%)	Fuel Flow (g/s)	<u>Exhaust Emissions</u>			H ₂ Mean Temp. (°C)
				HC (PPM)	CO (PPM)	NOx (PPM)	
486	1.63	133	.621	2.4	397	29	698
487	1.58	100	.620	4.2	594	40	701
488	1.62	74	.620	3.6	455	65	702
489	1.48	123	.625	10.8	1197	25	700
490	1.49	95	.622	6.0	1041	37	701
491	1.50	73	.621	4.8	1041	63	704
493	1.37	122	.639	4.2	2594	27	701
494	1.40	98	.637	2.4	2310	40	700
495	1.42	67	.632	1.2	1409	70	701
496	1.64	135	.626	1.8	310	33	702
497	1.64	110	.630	1.5	326	42	703
498	1.64	74	.624	1.2	277	68	700

TABLE 2
MAPPING & OPTIMIZATION SUMMARY

Simulation Point No. I (Re-Run)

(600 RPM, 5.4 kg-m Torque)

Run No.	Equiv. Ratio (X)	EGR (%)	Fuel Flow (g/s)	<u>Exhaust Emissions</u>			H ₂ Mean Temp. (°C)
				HC (PPM)	CO (PPM)	NOx (PPM)	
525	1.75	133	.603	1.8	277	26	696
526	1.76	116	.598	1.8	260	34	702
527	1.76	84	.598	1.2	260	53	702
529	1.55	140	.618	1.8	343	23	709
530	1.57	110	.604	1.2	397	36	701
531	1.56	74	.603	.6	476	52	712
532	1.47	136	.586	10.6	621	21	703
533	1.47	105	.582	7.2	931	29	700
534	1.47	78	.583	.6	1409	49	697
535	1.37	171	.606	3.6	1409	15	706
536	1.37	142	.550	3.0	2062	19	705
537	1.37	105	.586	1.8	2377	29	698

TABLE 3
MAPPING & OPTIMIZATION SUMMARY

Simulation Point No. I

(600 RPM, 5.4 kg-m Torque)

Temperature Affect on Fuel for Constant Emissions

Run No.	Equiv. Ratio (X)	EGR (%)	Fuel Flow (g/s)	<u>Exhaust Emissions</u>			H ₂ Mean Temp. (°C)
				HC (PPM)	CO (PPM)	NOx (PPM)	
478	1.52	144	.645	0	209	40	772
479	1.33	136	.630	2.4	569	37	771
480	1.20	125	.621	1.2	476	38	759
481	1.47	95	.613	1.2	594	41	739
482	1.49	114	.623	1.2	569	39	720
483	1.56	110	.608	1.8	498	40	700
484	1.59	109	.603	2.4	521	39	679
485	1.63	105	.595	2.4	521	40	659

TABLE 4
MAPPING & OPTIMIZATION SUMMARY

Simulation Point No. 4

(1000 RPM, 6.9 kg-m Torque)

Run No.	Equiv. Ratio (X)	EGR (%)	Fuel Flow (g/s)	<u>Exhaust Emissions</u>			H ₂ Mean Temp. (°C)
				HC (PPM)	CO (PPM)	NOx (PPM)	
467	1.68	168	1.077	1.8	260	31	732
468	1.67	128	1.002	1.8	293	41	729
469	1.69	75	.982	1.8	361	84	729
470	1.48	170	1.053	1.5	343	27	730
471	1.49	126	1.011	1.8	397	38	729
472	1.50	81	1.006	1.8	435	65	730
473	1.33	170	1.023	.6	862	22	731
474	1.33	131	.996	4.8	1197	31	730
475	1.35	82	.990	4.2	1322	60	730
499	1.67	167	1.087	2.4	260	30	730
500	1.69	138	1.051	1.8	277	39	730
501	1.69	70	1.015	1.8	378	81	730

TABLE 5
MAPPING & OPTIMIZATION SUMMARY

Simulation Point No. 4

(1000 RPM, 6.9 kg-m Torque)

-Temperature Affect for Constant Emission Level

<u>Run No.</u>	<u>Equiv. Ratio (X)</u>	<u>EGR (%)</u>	<u>Fuel Flow (g/s)</u>	<u>Exhaust Emissions</u>			<u>H₂ Mean Temp. (°C)</u>
				<u>HC (PPM)</u>	<u>CO (PPM)</u>	<u>NOx (PPM)</u>	
461	1.42	141	1.01	6.6	931	15	708
462	1.24	172	1.036	6.0	545	30	783
463	1.30	165	1.004	4.2	569	29	761
464	1.35	147	.991	3.6	521	30	743
465	1.43	136	.991	3.6	569	29	720
466	1.48	131	.994	4.2	569	30	699

TABLE 6
MAPPING & OPTIMIZATION SUMMARY

Simulation Point No. 5

(1100 RPM, 11.1 kg-m Torque)

Run No.	Equiv. Ratio (X)	EGR (%)	Fuel Flow (g/s)	<u>Exhaust Emissions</u>			H ₂ Mean Temp. (°C)
				HC (PPM)	CO (PPM)	NOx (PPM)	
452	1.63	130	1.45	1.2	171	52	767
453	1.63	86	1.39	1.2	151	87	763
454	1.63	69	1.36	.3	277	120	758
455	1.47	141	1.43	.6	260	35	763
456	1.42	103	1.38	.6	243	52	761
457	1.42	71	1.35	.6	260	91	753
458	1.3	148	1.41	.4	435	28	761
459	1.3	103	1.37	.6	435	47	761
460	1.3	73	1.36	.6	476	75	758
476	1.3	128	1.436	4.8	594	36	762
<u>(RE-RUN)</u>							
502	1.31	158	1.440	2.4	676	30	761
503	1.30	115	1.394	3.6	1117	42	759
504	1.32	80	1.380	.6	1689	67	760
505	1.31	92	1.383	3.6	1157	54	758
506	1.42	141	1.425	2.4	455	37	759
507	1.43	107	1.398	1.8	277	52	759
508	1.47	82	1.376	1.8	621	77	759
509	1.59	133	1.415	1.8	277	44	761
510	1.60	103	1.422	1.2	277	57	760
511	1.68	72	1.387	1.2	226	88	759

TABLE 7

MAPPING & OPTIMIZATION SUMMARY

Simulation Point No. 5

(1100 RPM, 11.1 kg-m Torque)

Temperature Affect For Constant Emission Level

Run No.	Equiv. Ratio (X)	EGR (%)	Fuel Flow (g/s)	Exhaust Emissions			H ₂ Mean Temp. (°C)
				HC (PPM)	CO (PPM)	NOx (PPM)	
136	1.43	111	1.40	.6	521	34	726
437	1.37	120	1.36	.3	521	32	746
438	1.43	112	1.40	6.0	1117	38	724
439	1.42	102	1.30	1.8	545	43	723
440	1.42	112	1.34	1.8	648	39	722
441	1.35	124	1.34	2.4	569	40	744
442	1.30	116	1.29	1.2	521	40	762
443	1.28	117	1.26	2.4	521	40	780
444	1.28	133	1.29	1.2	476	40	783
445	1.49	107	1.31	1.2	545	40	715
446	1.42	132	1.44	3.0	521	33	722
447	1.37	147	1.44	4.8	521	33	743
448	1.30	148	1.37	1.2	521	32	762
449	1.24	178	1.42	4.8	521	32	783
450	1.43	141	1.44	4.2	521	32	724
451	1.47	136	1.44	3.6	521	31	702

TABLE 8MAPPING & OPTIMIZATION SUMMARY

Simulation Point No. 6

(1300 RPM, 15.9 kg-m Torque)

Run No.	Equiv. Ratio (X)	EGR (%)	Fuel Flow (g/s)	<u>Exhaust Emissions</u>			H ₂ Mean Temp. (°C)
				HC (PPM)	CO (PPM)	NO _x (PPM)	
417	1.44	90	2.0	3.6	545	54	726
418	1.43	48	1.94	3.6	797	120	725
419	1.45	59	1.91	.6	705	84	726
420	1.31	61	1.94	1.8	1197	78	724
421	1.30	39	1.91	7.2	1949	132	720
422	1.32	104	1.96	.6	931	39	725
423	1.44	98	2.0	.6	931	50	727
424	1.44	62	2.0	3.3	1003	88	724
425	1.57	64	2.07	2.4	662	95	727
426	1.6	41	1.96	3.0	648	150	727
427	1.61	116	2.08	3.0	498	460	718

TABLE 9MAPPING & OPTIMIZATION SUMMARY

Simulation Point No. 6 (Re-Run)

(1300 RPM, 15.9 kg-m Torque)

<u>Run No.</u>	<u>Equiv. Ratio (X)</u>	<u>EGR (%)</u>	<u>Fuel Flow (g/s)</u>	<u>Exhaust Emissions</u>			<u>H₂ Mean Temp. (°C)</u>
				<u>HC (PPM)</u>	<u>CO (PPM)</u>	<u>NOx (PPM)</u>	
514	1.33	108	1.969	1.8	498	53	759
515	1.33	72	1.922	1.8	734	85	758
516	1.33	140	1.956	1.2	476	38	758
517	1.46	118	1.949	1.2	343	39	759
518	1.46	98	1.900	.9	361	60	753
519	1.46	69	1.876	1.2	397	97	750
520	1.67	105	1.978	1.2	243	59	757
521	1.69	101	1.973	1.2	243	63	754
522	1.71	78	1.921	1.2	243	89	752

TABLE 10
4-215 STIRLING ENGINE
MAPPING & OPTIMIZATION SUMMARY

Simulation Point No. 6

(1300 RPM, 15.9 kg-m Torque)

Temperature Affect on Fuel Flow

<u>Run No.</u>	<u>Equiv. Ratio (X)</u>	<u>EGR (%)</u>	<u>Fuel Flow (g/s)</u>	<u>HC (PPM)</u>	<u>CO (PPM)</u>	<u>NOx (PPM)</u>	<u>Mean Temp. (°C)</u>
428	1.42	91	2.02	1.5	862	53	724
429	1.43	90	2.01	.6	734	57	740
430	1.43	88	1.99	.6	676	62	743
431	1.35	91	1.97	.06	648	60	765
432	1.34	91	1.97	.09	734	60	783
433	1.52	74	2.07	.9	765	60	704
<u>RECHECK</u>							
434	1.44	96	2.14	2.4	594	48	726
435	1.32	86	1.99	.6	569	63	767

4-215 STIRLING ENGINE

FUEL FLOW
VS
HYDROGEN TEMPERATURE

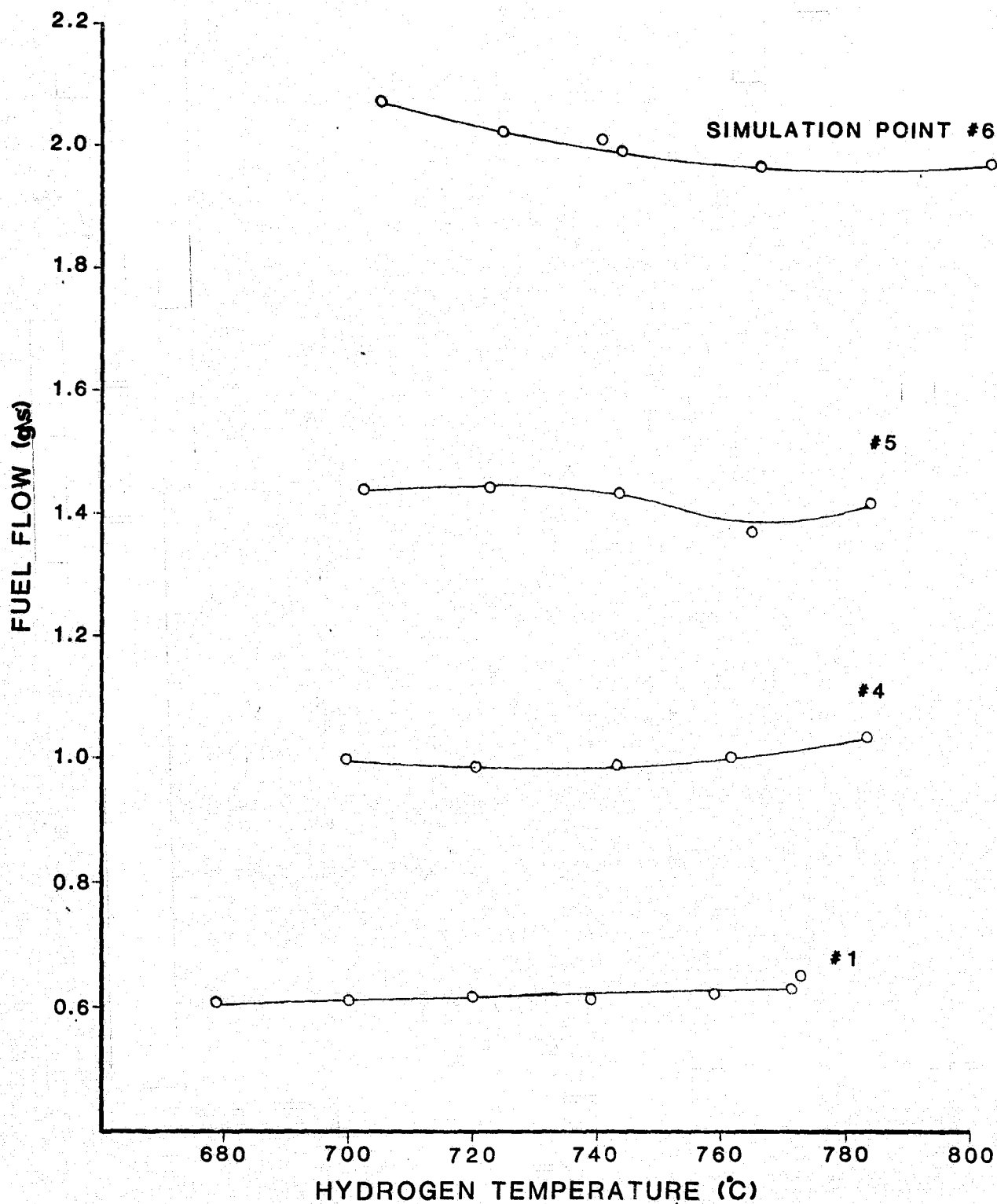
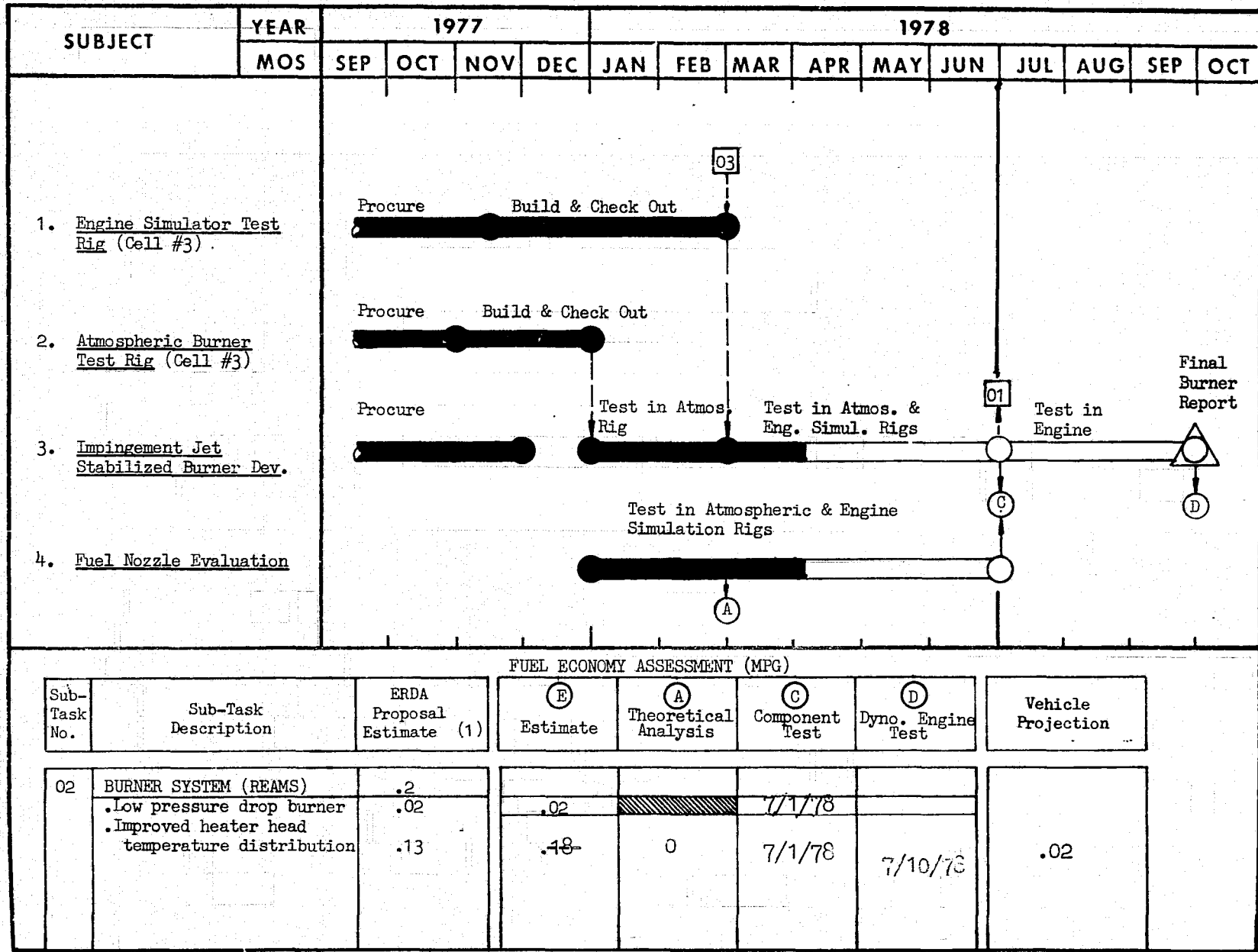


FIGURE 1

SUB-TASK 02 BURNER SYSTEM



BURNER SYSTEM - SUB-TASK 02

Assembly of the Engine Simulator Test Rig was completed. The rig was initially checked out using the baseline burner system hardware and the Excello fuel nozzle. A problem was experienced with the cooling air valve response when the rig was operated in the manual blower throttle control mode. This problem is being investigated. Despite this problem, some testing was performed. The rig was successful at fuel flows of approximately 3.25 g/s, the maximum flow encountered during simulation point testing of the CVS driving cycle.

The baseline burner system with the Philips pintle and Excello fuel nozzles was tested on the Atmospheric Burner Test Rig. A Test Summary (PTS-098) describing the results of this testing was written and submitted to NASA. A synopsis of this Test Summary is included (refer to Attachment 2).

The video-tape recorder system which will be used to monitor and create visual records of testing on the Atmospheric Burner Test Rig was received.

Additional testing of the impingement jet stabilized (IJS) combustor with both Philips and Excello fuel nozzles was carried out. Both hardware combinations exhibit asymmetric flame patterns and, at times, unstable operation.

A modified IJS combustor, having a different arrangement of impingement jet holes, has been fabricated. This combustor was fabricated due to initial results from the Atmospheric Rig tests. These results indicated that the combustor, as originally designed, gives inadequate primary zone swirl and does not provide for the intended interior recirculation pattern.

Testing of the Philips and Excello fuel nozzles in the Atmospheric and Burner Rigs is continuing.

FUEL ECONOMY ASSESSMENT

The assessed maximum fuel economy improvement opportunity of Burner System, sub-task 02, remained unchanged at 0.20 MPG (gasoline).

SYNOPSIS OF TEST SUMMARY PTS-098

"Atmospheric Burner Rig Testing"

Objective:

To qualitatively evaluate various combustion system hardware combinations.

Description:

This Test Summary reports on the results of preliminary tests carried out on the baseline burner system hardware, and the baseline system with the Excello fuel nozzle.

Results:

Operation of the baseline hardware with both the Philips and Excello nozzles was qualitatively satisfactory at fuel flows > 1 g/s. At 1 g/s fuel or less, both systems exhibited problems in maintaining stable combustion and/or satisfactory atomization.

Discussion:

Tables 1 and 2 present the results of atmospheric rig testing for test series 1-01 and 3-01, respectively. Figure 1 provides a description of the schematic sketch used in Tables 1 and 2 to describe the appearance of the flame profile when viewed from the end of the exhaust barrel. In addition, Table 3 provides a description of the various qualitative terms used to describe the swirl, atomization, and flame appearance for any particular test point.

With the exception of test points 26 and 28, air assist pressure for the Philips nozzle was maintained at or near the value used during dyno testing, .66 atm (20" Hg). For test point 26, the assist pressure was set at 0.5 atm and 1.34 atm for point 28. The low assist pressure gave rise to poor atomization with the result that fuel was observed burning on the surface of the combustor. The higher assist pressure of run 28 resulted in a somewhat more compact swirl than in run 27 (for the same fuel flow) and also contributed to a stabilization of the combustion. Frequent blowout was noted in run 27, but not in 28. Run 32 is similar to 29 except that air excess was increased.

When using the Excello nozzle with the other baseline hardware, the majority of the testing was done at an air assist pressure at the nozzle of about .5 atm (15" Hg). Although generally lower than the pressures required for the Philips nozzle, the design of the Excello nozzle permits substantially higher mass flows. Figure 2 shows the relationship between upstream flow orifice pressure and pressure at nozzle discharge for both the Philips and Excello nozzles. Test runs 14 and 15 were conducted at essentially the same fuel flows and excess air ratios, but at quite different values of air assist pressure/flow. Note the differences in swirl and atomizing quality between the two runs.

At .5-.66 atm air assist nozzle pressure, substantial back pressuring of the fuel takes place in the Philips nozzle while no noticeable back pressure is present using the Excello nozzle. The Philips nozzle was operated at an air assist pressure of

.66 atm because at this time this is the pressure used in dynamometer testing in order to achieve satisfactory light-off and combustion. The assist pressure and flow used during the Excelllo nozzle tests exceeds the capability of the current electric atomizing pump used in vehicle testing. Refer to Figure 3 for descriptive curves relating flow and Δp for the Excelllo nozzle and the Gast atomizing pump. Also, note the location of test run 14 on Figure 3 and the test results in Table 2 for the same run.

Operation of the Philips nozzle at fuel flows of .4/.5 g/s was unstable at λ values of 1.3-1.5. Even at $\lambda \approx 1.9/2.0$, frequent blowout/relight occurred. At corresponding conditions using the Excelllo nozzle no blowout occurred but pulsations in the flame were noted.

The predominant flame color during most of the test runs was a luminous yellow/yellow-orange, indicating the oxidation of free carbon atoms.

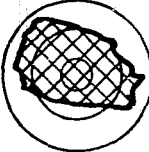
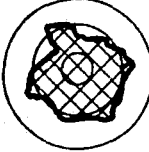
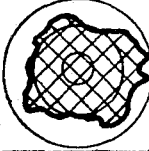
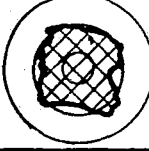
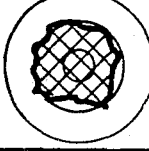
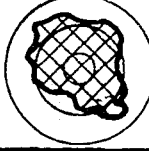
Hardware/Instrumentation:

Test rig, auxiliary equipment, and hardware to be evaluated as detailed in the Atmospheric Burner Rig Test Plan (TP-9).

Baseline Hardware &
Philips Fuel Nozzle

TABLE 1
ATMOSPHERIC BURNER TEST RIG RESULTS

Test Series: 1-01

Run No.	Air Assist Pressure (Atm.)	Air Assist Flow (g/s)	Swirl Quality	Atomizing Quality	Vortair Burner	Flame Quality Color	Flame Profile	Additional Comments
26	0.50	0.65	Strong, but not compact	Instances of fuel burning on combustor surface	1.92	Frequent blowout		Difficult to maintain stable combustion at values near 1.3-1.5
0.42					2.03	Yellow-orange		
27	0.67	0.74	Strong, but not compact	Good	1.40	Frequent blowout		Very unstable flame
1.01					1.45	Yellow-orange		
28	1.34	1.17	Strong, more compact than #27	Good	1.40	Stable flow		Flame appears stronger than in run #27
1.01					1.48	Yellow-orange		
29	0.69	0.7	Weak	Good	1.45	Stable flow		
2.04					1.48	Yellow-orange		
30	0.72	0.69	Weak	Good	1.35	Stable flow		Flame extends well into barrel
3.03					1.37	Yellow-white		
32	0.66	0.66	Strong, but not compact	Good	2.00	Stable		Compare to run #29
2.02					2.02	Yellow-hint of blue		

Baseline hardware
& Excello nozzle

TABLE 2
ATMOSPHERIC BURNER TEST RIG RESULTS

Test Series: 3-01

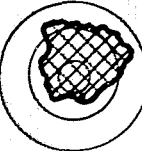
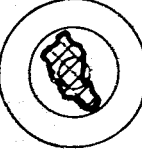
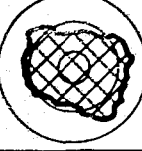
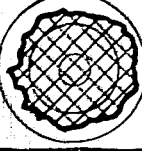
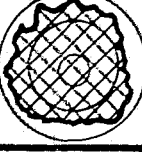
Run Number	Air Assist Pressure (Atm)	Air Assist Flow (g/s)	Swirl Quality	Atomizing Quality	Vortair Burner	Flame Quality Color	Flame Profile	Additional Comments
14	0.13	0.62	Weak, varying	Fuel burning on combustor surface	1.75	Stable flow		Swirl is definitely unstable - varying
0.50					1.83	Yellow-orange		
18	0.51	1.53	Strong, compact	Good	1.78	Pulsating		
0.45					2.01	Blue-yellow		
19	0.52	1.54	Strong	Good	1.41	Pulsating		
1.05					1.52	Yellow		
20	0.52	1.52	Weak	Good	1.52	Stable flow		
1.99					1.57	Yellow		
21	0.51	1.53	Weak	Good	1.39	Stable flow		Flame extends far into barrel
3.04					1.43	Yellow		
25	0.52	1.54	Strong, but not compact	Good	1.88	Stable flow		
3.25					1.92	Yellow		

TABLE 3

SWIRL

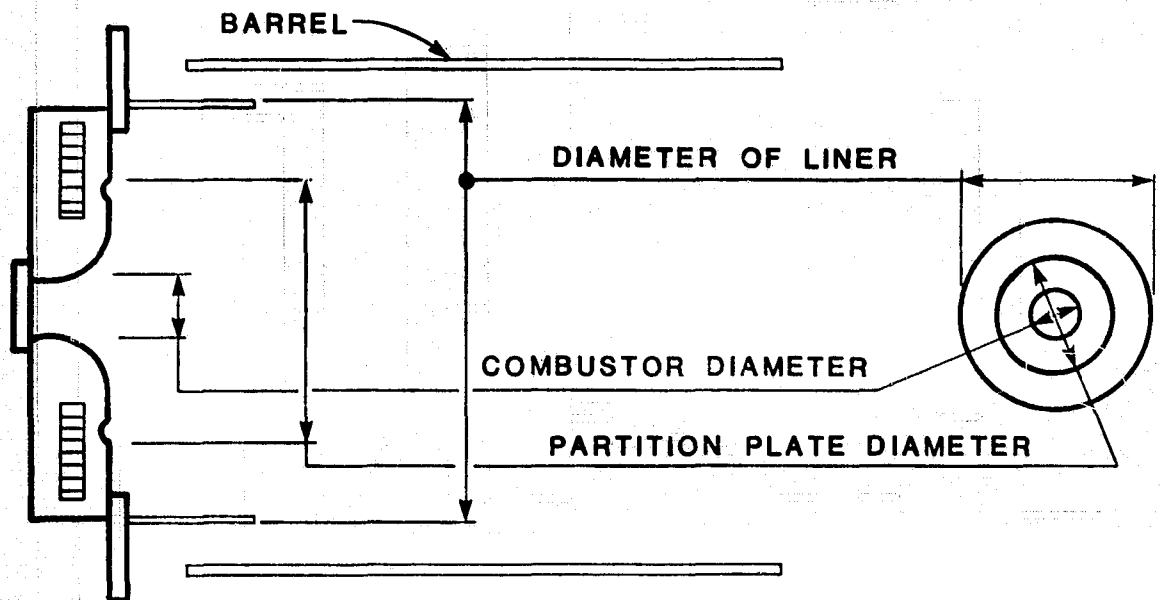
Strong: Swirl is strong and well developed;
Weak: Swirl is not well developed;
Varying: Swirl varies or changes with time;
Compact: Swirl is well tucked up into combustor can.

ATOMIZING

Considered good if there is no indication of fuel burning on inside surface of combustor or burning in obvious streaks emanating from combustor. In severe instances of poor atomization, raw fuel may also be observed on the sides of the combustor.

FLAME

Stable: In general, combustion is steady with time;
Pulsating: Flame exhibits a tendency to shrink and grow in intensity with time;
Burnout: Flame extinction and re-light.



SKETCH SHOWING RELATIONSHIP BETWEEN RIG COMPONENTS &
SCHEMATIC DIAGRAM USED TO DESCRIBE FLAME PROFILE

FIGURE 1

UPSTREAM ORFICE PRESSURE * VS. PRESSURE AT FUEL NOZZLE FOR N.V.P. AND EXCELLO NOZZLES

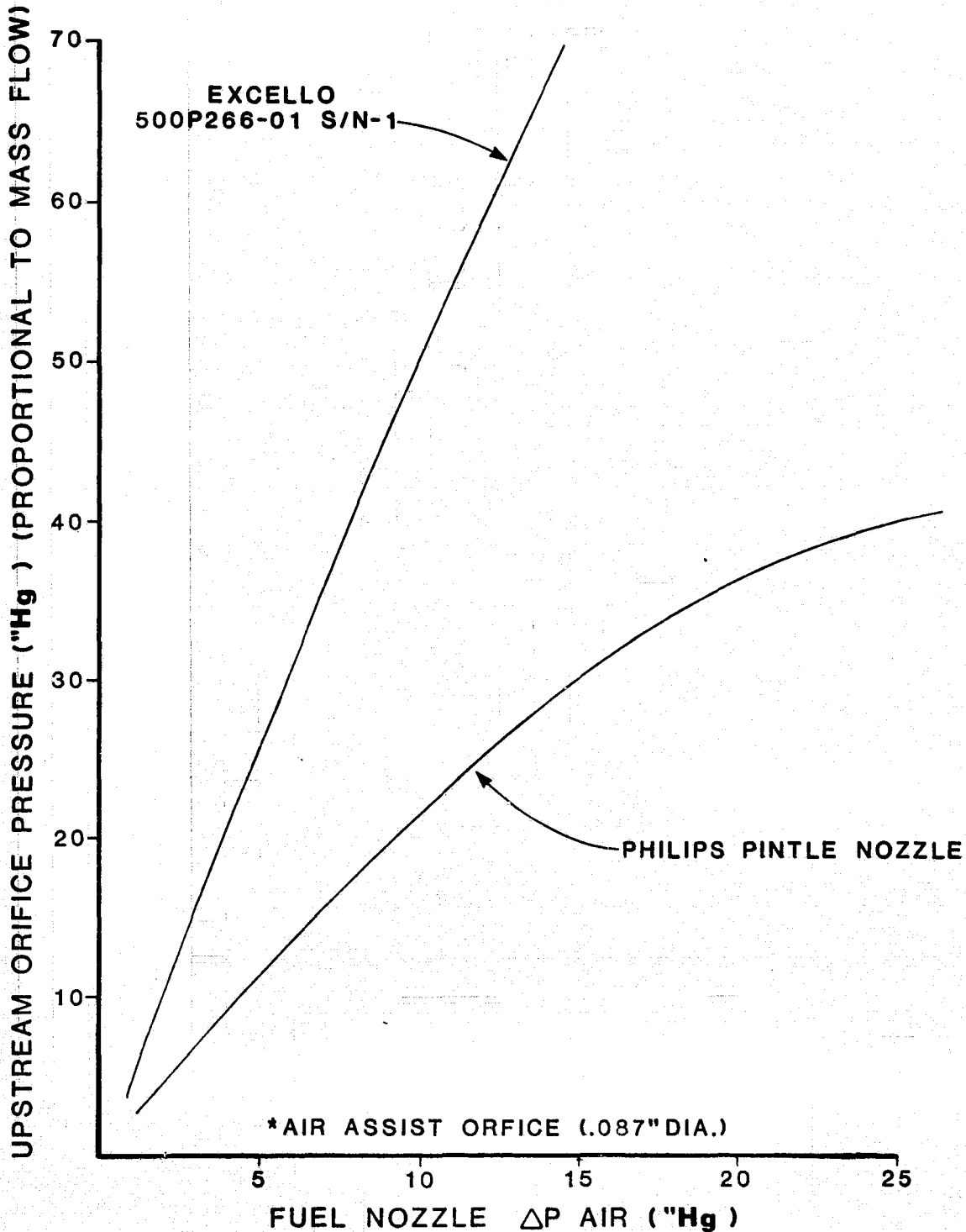


FIGURE 2

AIR FLOW VS NOZZLE ΔP FOR EXCELLO FUEL NOZZLE AND GAST PUMP

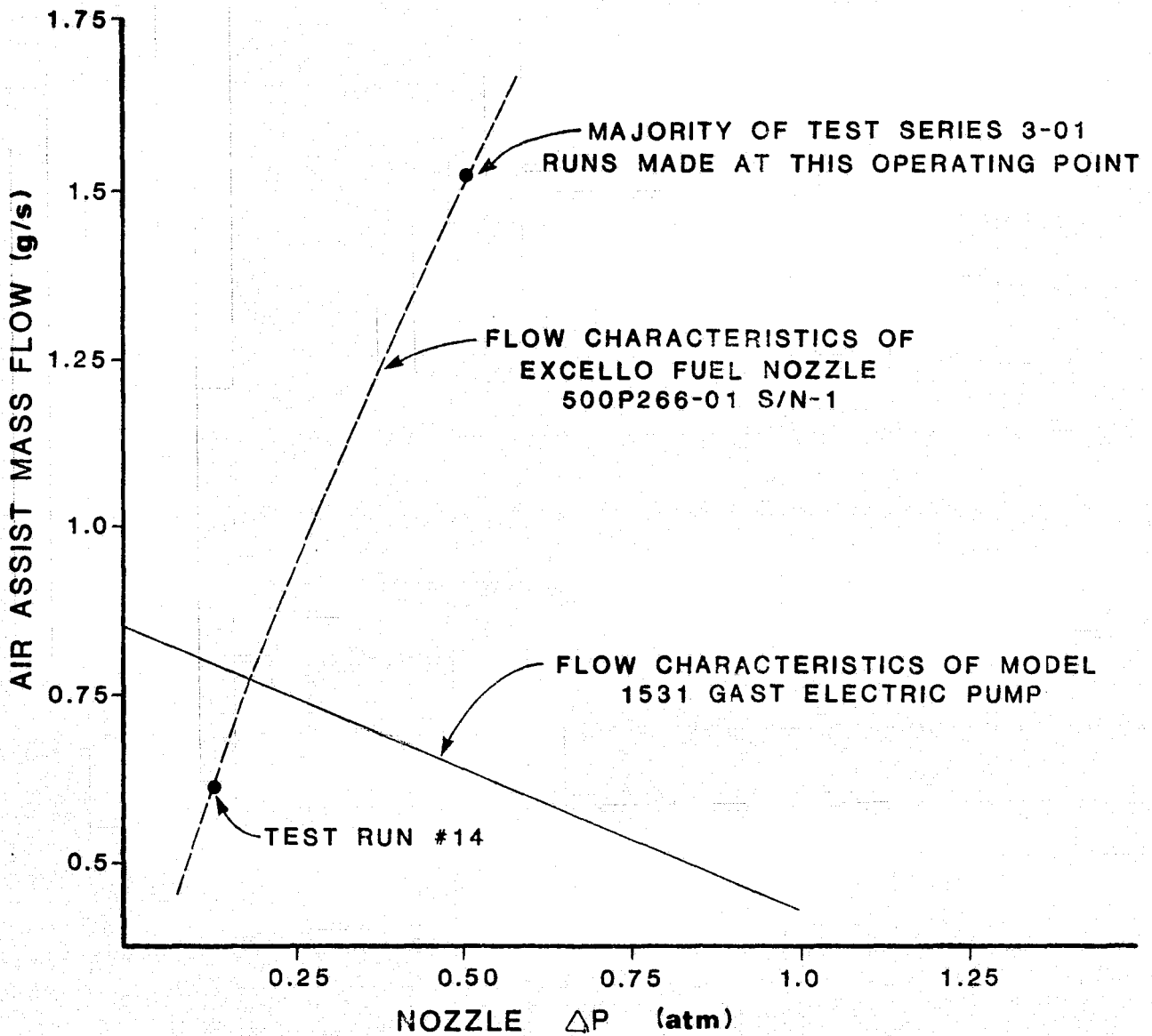
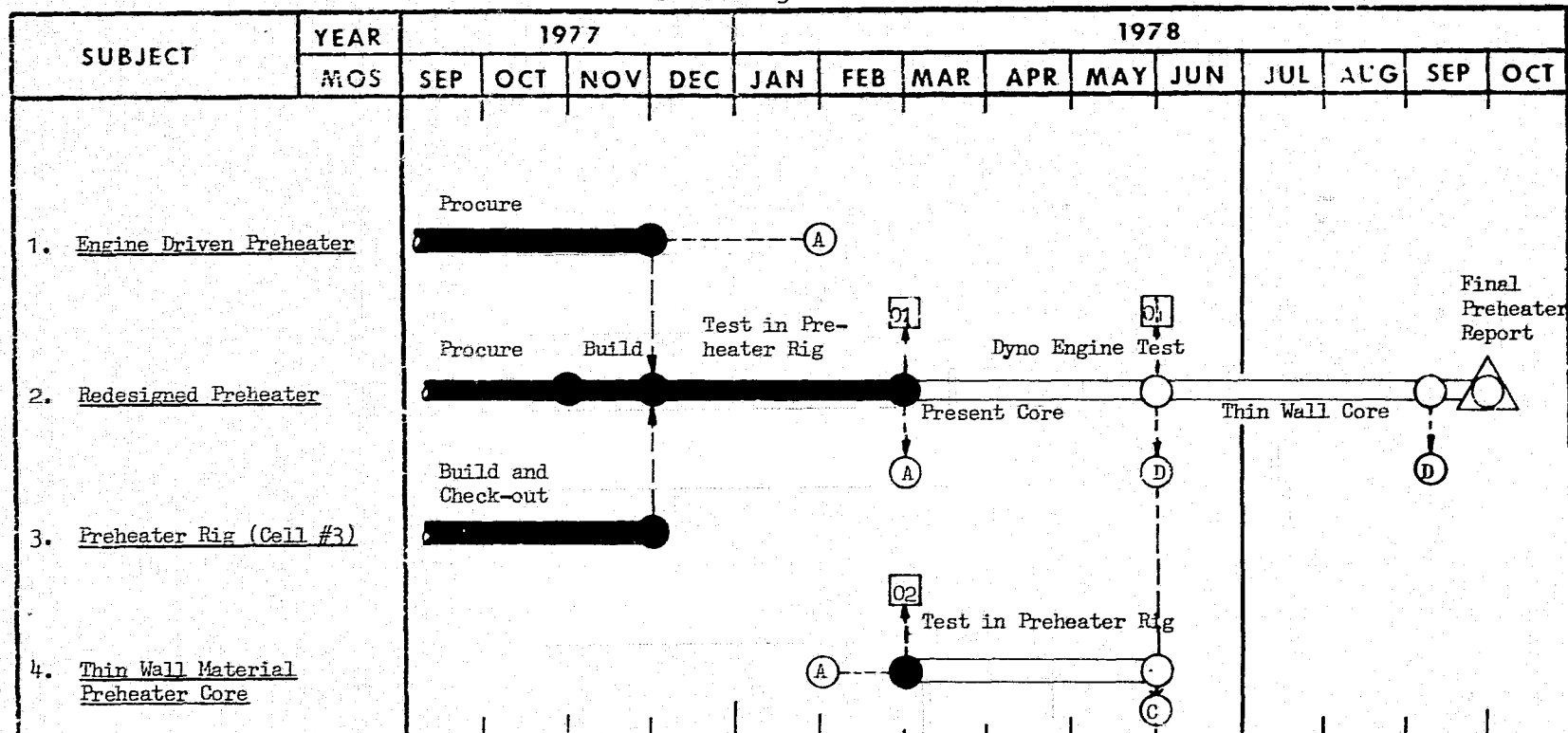


FIGURE 3

SUB-TASK 03 PREHEATER



FUEL ECONOMY ASSESSMENT (MPG)

Sub-Task No.	Sub-Task Description	ERDA Proposal Estimate (1)	(E) Estimate	(A) Theoretical Analysis	(C) Component Test	(D) Dyno. Engine Test	Vehicle Projection
03	PREHEATER (REAMS)	.3					
	.Engine driven preheater	.14	.14	.16	7/15/78		.44
	.Thin wall material pre-heater core	.14	-	.26/70%	7/10/78		
	.Seal friction reduction	.01	.00				
	.Reduced preheater leakage	.02	.02		7/15/78		

PREHEATER DEVELOPMENT - SUB-TASK 03

Work on the engine driven preheater was completed.

The preheater drive motor, with the overriding clutch, is ready for test on the dynamometer engine.

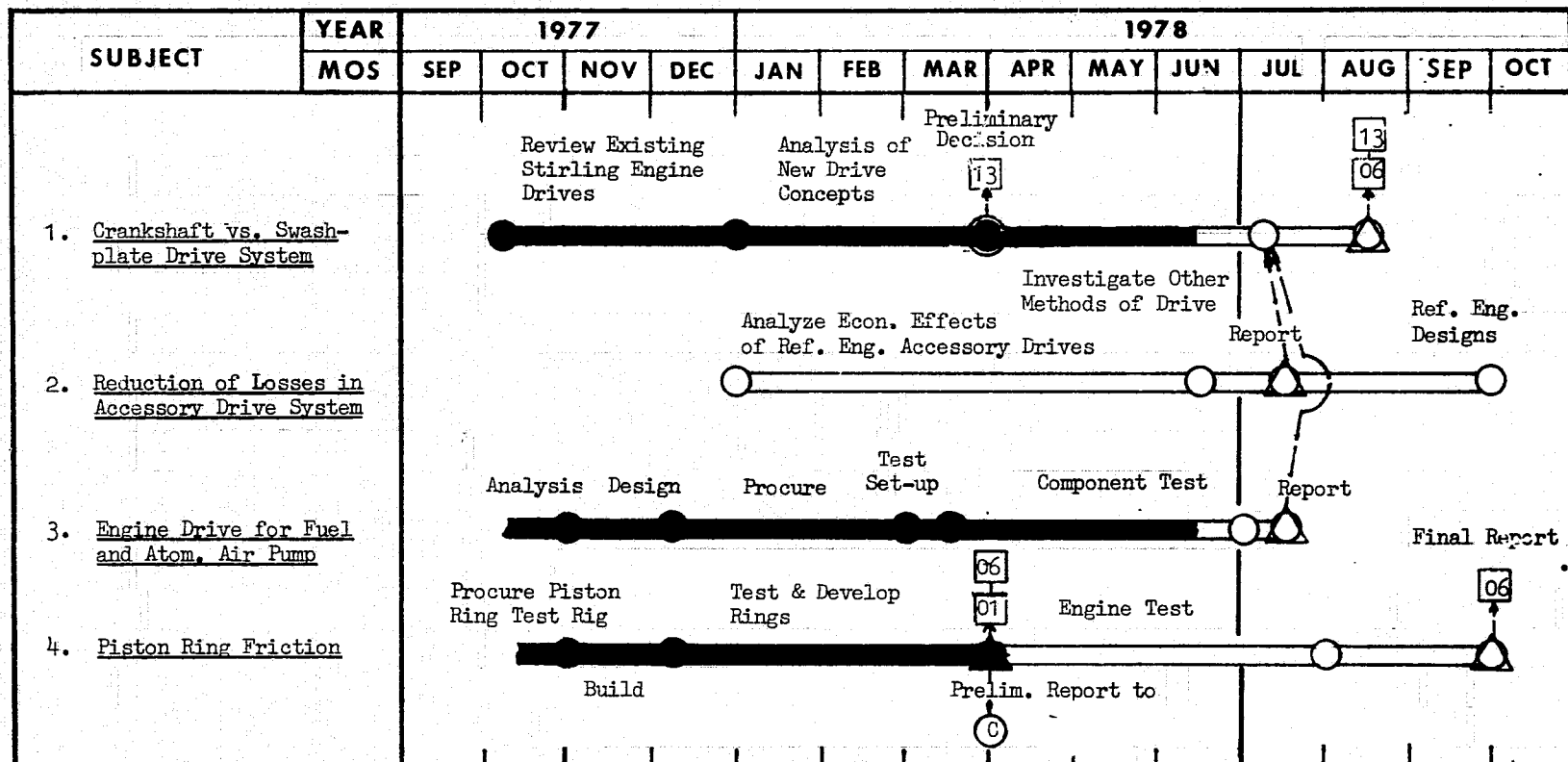
The redesigned preheater assembly is ready for test on the dynamometer engine.

The thin wall preheater cores are ready for testing on the Preheater Test Rig.

FUEL ECONOMY ASSESSMENT

The assessed maximum fuel economy improvement opportunity of Preheater Development, sub-task 03, remained unchanged at 0.18 MPG (gasoline).

SUB-TASK 04 ENGINE DRIVE STUDY



FUEL ECONOMY ASSESSMENT (MPG)

Sub-Task No.	Sub-Task Description	ERDA Proposal Estimate(1)	(E) Estimate	(A) Theoretical Analysis	(C) Component Test	(D) Dyno. Engine Test	Vehicle Projection
04	ENGINE DRIVE STUDY (KANTZ)	.2					
	. Crankshaft vs Swashplate	.10		+1.10			
	. Accessory drive	.05	.08	9/1/78			1.69
	. Engine drive for fuel and atom. air pump	-		+ .27	7/1/78		
	. Piston ring friction	-		.24	7/1/78	8/1/78	

ENGINE DRIVE STUDY - SUB-TASK 04

A preliminary stress analysis of the swashplate in the 4-215 Stirling engine indicated that the swashplate could be reduced in thickness by approximately 0.9 in. (2.29 cm) and still retain adequate strength. This would allow the crossheads to be shortened by the same thickness, thereby increasing their stiffness. The original thickness of the swashplate was established to provide space to house tungsten weights for engine inertia balance. Smaller weights are now employed and have been placed near the ends of the mainshaft.

The swashplate drive system was redesigned because of the stress analysis and the fact that the crossheads were binding in their bores. This redesign was accomplished by incorporating the following changes:

- a. Reducing the swashplate thickness to a minimum to allow shortening of the crosshead bridge for greater stiffness.
- b. Providing a slightly barrel-shaped surface at each end of the crossheads, permitting them to deflect under the action of a tensile force without contacting the cylinder bores (see figure II-2).
- c. Providing a pinned joint between the crosshead and piston rod, eliminating any moment from being transmitted through the connecting rod.

Detail drawings of the new swashplate drive system are being prepared.

The M-H fuel economy projection for the dual crankshaft engine has been increased by 0.05 MPG to account for the lack of accessory drive losses in this engine (i.e., there is no drive chain or accessory shaft). The M-H fuel economy projection for the dual crankshaft engine is now 15.9 MPG (gasoline). This compares with a fuel economy projection of 16.17 MPG for the swashplate drive as calibrated by the Philips analytical program.

An analysis of the dual-crank engine was initiated to determine what problems might be encountered in balancing the engine.

Engine Drive Study - Sub-task 04 (Continued)

The Air Atomizer Pump Test Rig was completed (see figure II-3). A Gast air atomizer pump (model 1AM-NCW-14) was tested and found to be inadequate for the desired application. A Test Summary (PTS-106) was written describing the results of this test. A synopsis of this Test Summary is included (refer to Attachment 3).

The strain gage columns in the Piston Ring Test Rig were replaced with piezoelectric force transducers. This was done in an effort to eliminate the fixture vibration which was causing poor oscilloscope readings. However, the poor readings continued, necessitating the installation of a 150 Hz filter to block the high frequency vibrations. Figure II-4 illustrates the effect of the filter.

Test results from the standard and pressure balanced piston rings made from Rulon LD and Rulon J indicate the following:

- a. Pressure balancing the piston rings will result in a reduction of friction which correlates with the calculated values.
- b. The friction of Rulon J is less than that of Rulon LD.
- c. The gas leakage by the pressure balanced piston rings is significantly greater than with the standard rings. Analysis indicates that there will be a net loss in fuel economy with the pressure balanced rings as presently designed.

The scarf-type of piston ring joint (see figure II-5) is poor with respect to sealing characteristics and reliability. A step joint ring could result in lower leakage and the use of Rulon J would result in a reduction of friction. Rings of this type have been ordered for testing.

FUEL ECONOMY ASSESSMENT

The assessed maximum fuel economy improvement opportunity of Engine Drive Study, sub-task 04, was increased during this reporting period from 0.74 MPG to 1.64 MPG (gasoline). This increase is attributable to the new crosshead design.

SYNOPSIS OF TEST SUMMARY PTS-106

"Air Atomizer Pump Test"

Objective:

- 1) To determine the mechanical power requirements to drive the Air Atomizer pump, Gast model 1AM-NCW-14
- 2) To determine if air pressure and air flow capacity is adequate for use with the Stirling engine.

Results:

The mechanical power to drive the air atomizer was 80% lower than expected.

Air pressure and air flow were 3% and 16% respectively, of the minimum acceptable values as defined in Engineering Note PEN-143.

Conclusion:

The pump is unacceptable for use with the 4-215 Stirling engine due to inadequate flow capacity and pressure. See attached data sheet.

AIR ATOMIZER DATA SHEET

To obtain flow, pressure, and torque

Pump Manufacturer: Gast

Pump model number: 1AM-NCW-14

RUN NO.	(RPM)	PRESSURE IN. Hg./psi	TORQUE gm-cm/HP	FLOW (CFM)
	500	0	0	0
	1000	0	0	0
	1500	.3"Hg./.15	120/300	0
	2000	.45"Hg./.22	150/.004	0
	2500	.6"Hg./.29	180/.006	0
	3000	.75"Hg./.37	210/.009	.58
	3500	.9"Hg./44	240/.012	.62
	4000	1.15"Hg/.56	270/.016	.72
	4500	1.35"Hg./.66	320/.021	.80
	5000	1.5"Hg/.73	370/.027	.89
	5500	1.8"Hg/.88	440/.035	.97
	6000	2.0"Hg/.98	500/.044	1.05
	6500	2.3"Hg/1.12	560/.053	1.13

NEW CROSSHEAD DESIGN

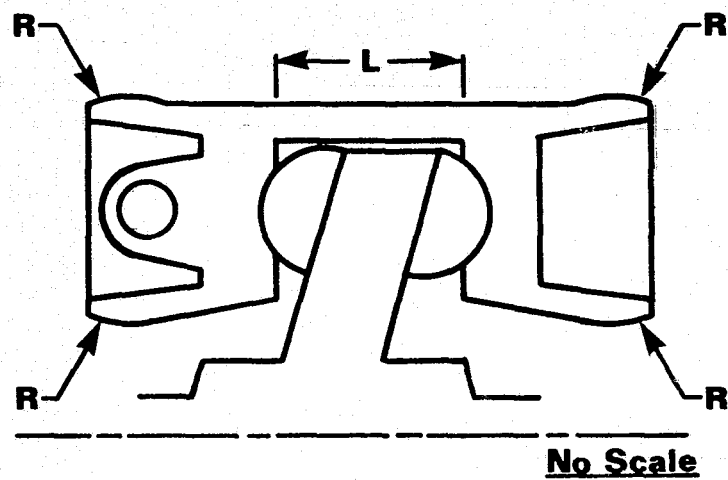
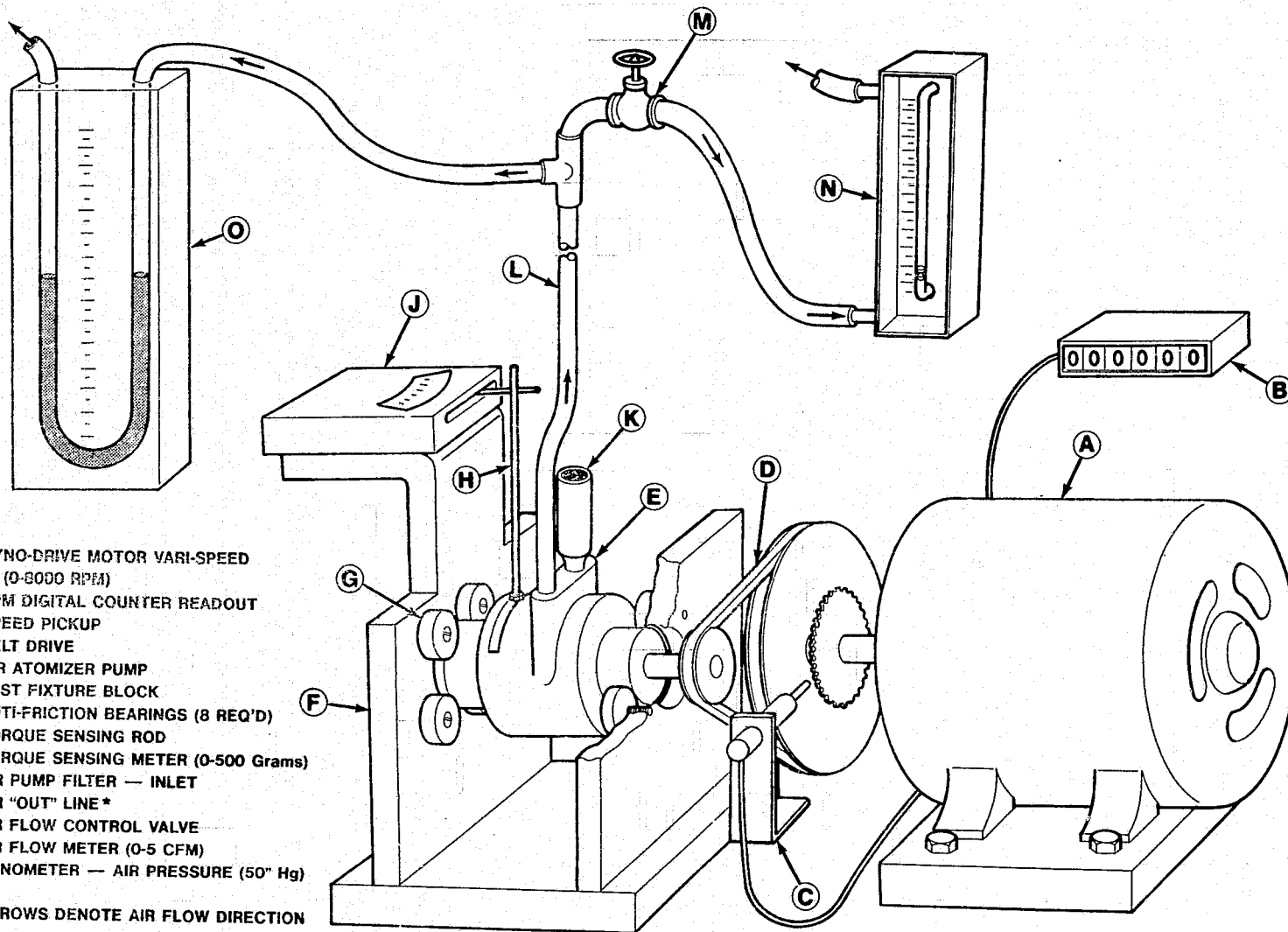


FIGURE II-2

AIR ATOMIZER PUMP TEST RIG SCHEMATIC



- A DYNO-DRIVE MOTOR VARI-SPEED (0-8000 RPM)
 - B RPM DIGITAL COUNTER READOUT
 - C SPEED PICKUP
 - D BELT DRIVE
 - E AIR ATOMIZER PUMP
 - F TEST FIXTURE BLOCK
 - G ANTI-FRICTION BEARINGS (8 REQ'D)
 - H TORQUE SENSING ROD
 - J TORQUE SENSING METER (0-500 Grams)
 - K AIR PUMP FILTER — INLET
 - L AIR "OUT" LINE*
 - M AIR FLOW CONTROL VALVE
 - N AIR FLOW METER (0-5 CFM)
 - O MANOMETER — AIR PRESSURE (50" Hg)
- ARROWS DENOTE AIR FLOW DIRECTION
- *ALL LINES ARE FLEXIBLE TUBING

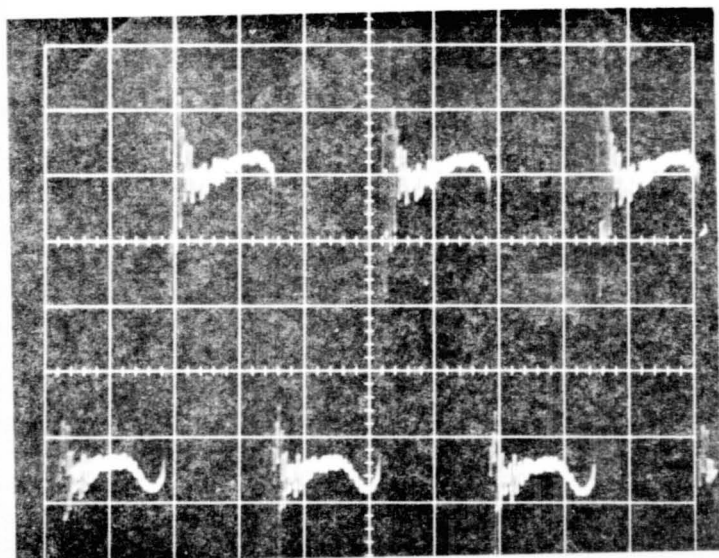
FIGURE II-3

FILTER EFFECT ON FRICTION MEASUREMENT

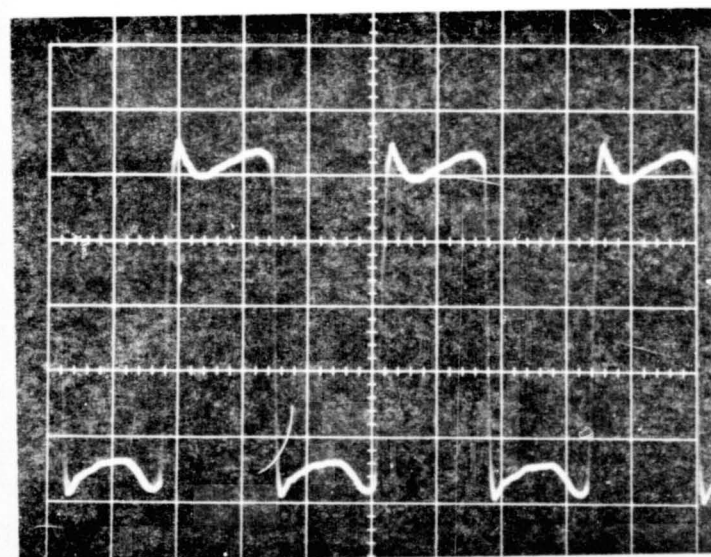
Speed - 900 cps

Pressure - 850 psig

Piezoelectric Force Transducer



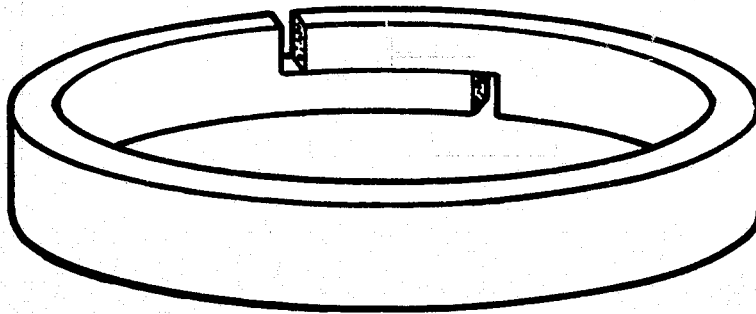
Oscilloscope Display of Transducer Output



Filtered Transducer Output (150 Hz)

PISTON RING JOINTS

STEP JOINT



DIAGONAL SCARF JOINT

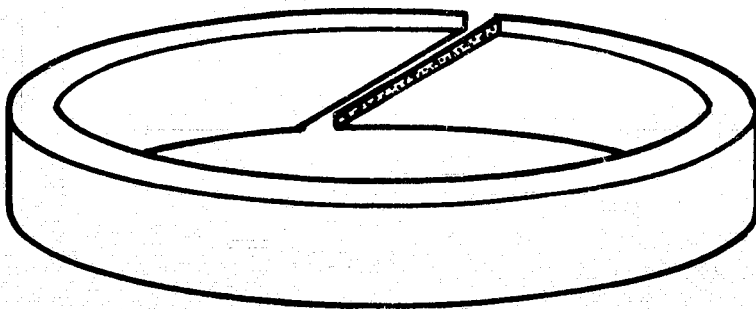
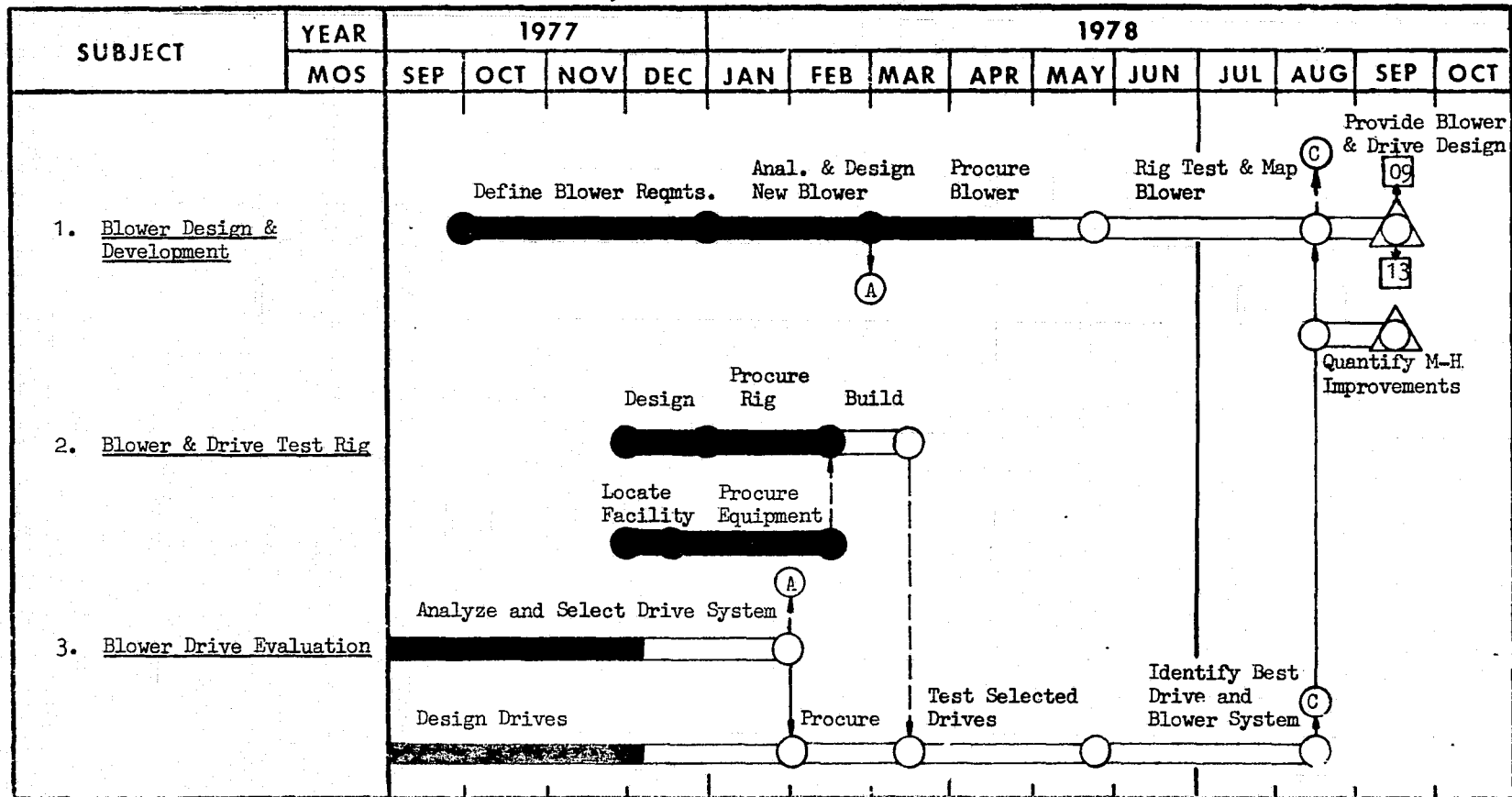


FIGURE II-5

SUB-TASK 05 EXTERNAL HEAT AND BLOWER SYSTEM



FUEL ECONOMY ASSESSMENT (MPG)

Sub-Task No.	Sub-Task Description	ERDA Proposal Estimate (1)	(E) Estimate	(A) Theoretical Analysis	(C) Component Test	(D) Dyno. Engine Test	Vehicle Projection
05	EXTERNAL HEAT AND BLOWER SYSTEM (KANTZ)	.1					.46
	.Improved blower design	.04	.06	.11	9/1/78		
	.Improved blower drive	.05	.08	9/1/78			
	.Reduce air flow reqmts. (Ref. Sub-task 10)	-	-	.27	9/1/78		

EXTERNAL HEAT AND BLOWER SYSTEM - SUB-TASK 05

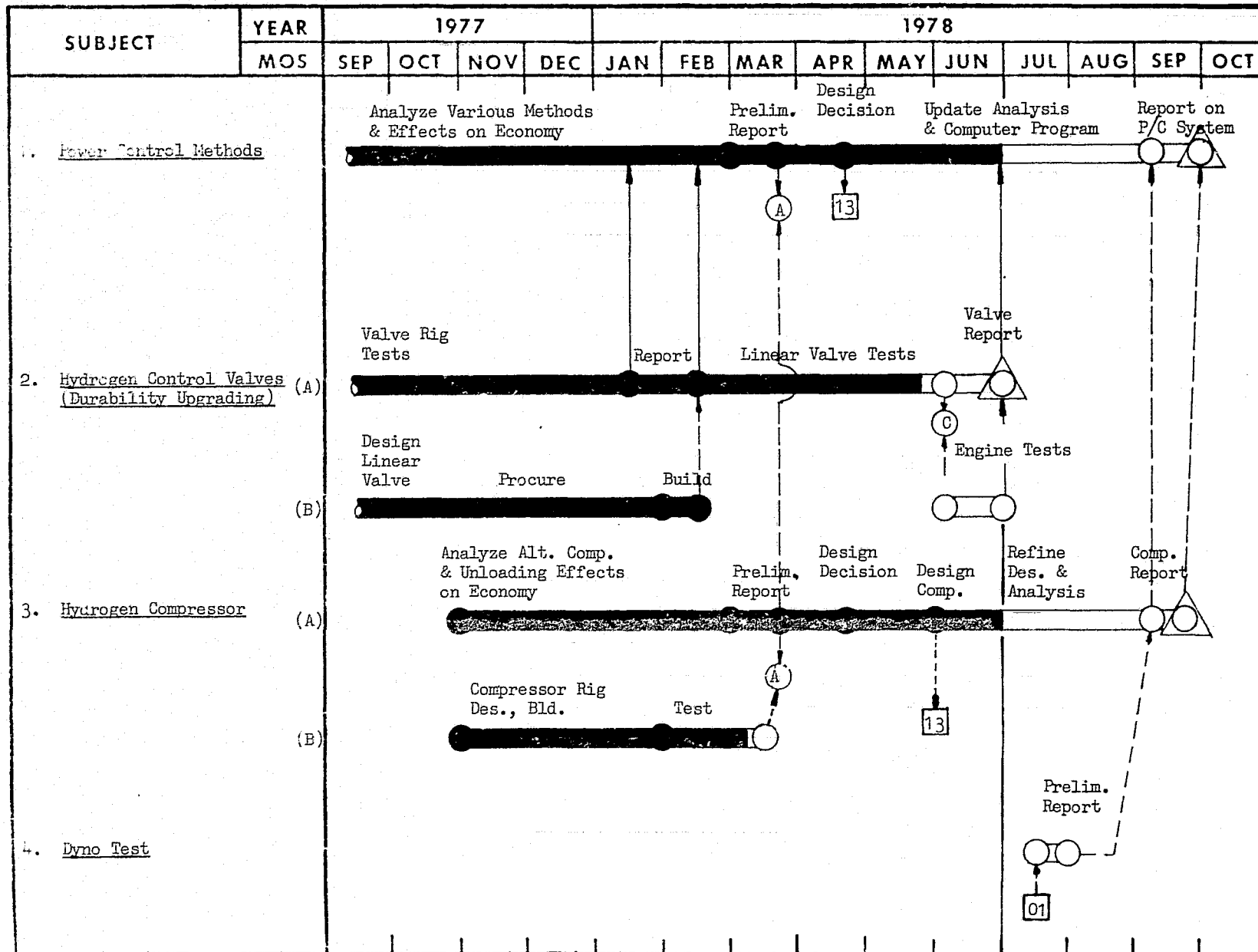
Layout and detailing on the new blower design has been completed. The design of the vaneless diffuser and collector scroll deviates slightly from those in the design submitted by the blower consultant retained by Ford; however, the impeller design is unchanged. The changes allowed reducing the blower outside diameter 3.9 inches from the current blower, and approximately 4.0 inches from the consultant's design. There may be a slight reduction in performance due to the changes but the reduction in blower diameter is considered to be of greater significance.

The drawings of the housing and impeller have been checked and an order was placed for three sets of housing castings and three impeller assemblies, three shafts, and three pulleys.

FUEL ECONOMY ASSESSMENT

The assessed maximum fuel economy improvement opportunity of External Heat and Blower System, sub-task 05, remained unchanged at 0.46 MPG (gasoline).

SUB-TASK 08 POWER CONTROL SYSTEM



SUB-TASK 08 POWER CONTROL

Sub-Task No.	Sub-task Description	ERDA Proposal Estimate (1)	(E) Estimate	(A) Theoretical Analysis	(C) Component Test	(D) Dyno. Engine Test	Vehicle Projection
08	POWER CONTROL SYSTEM (Kosacheff)	.9					1.39
	.Hydrogen compressor plunger friction	.85		.55	8/30/78	7/30/78	
	.Hydrogen distributor friction	.05	.05	8/31/78			
	.Sealed piston dome	.05 (2)		.00			
	.Reduce power losses of power control actuator needed for fast transient response	-			+.02		
	.Eliminate "short circuiting" power losses during decelerations	-		+.03			
	.Alternate power control	-		.74			

POWER CONTROL - SUB-TASK 08

Engineering Notes PEN-159 and PEN-160 were written during this reporting period. PEN-159 summarizes the procedure and result of control component sizing. PEN-160 summarizes the control dead volume valve area computer program and results obtained thus far. A synopsis of each of these Engineering Notes is attached (refer to Attachments 4 and 5).

Figure II-6 illustrates a control dead volume module of 308 cc ($X_c = 1.42$) that can be used on the 4-215 engine with minor engine modifications.

The linear power control valve testing indicated leakage across the transfer valve portion. Because the transfer valve function is not an essential operation, it has been sealed off and the function will be performed externally with an existing valve. Indications are that spool friction is low.

The 4-215 linear power control module was tested. The results are:

- a. Cycling tests have indicated no sealing deterioration after 10,300 full stroke cycles for eight of the nine seals. The ninth seal developed an excessive leak at 3600 cycles. A new seal ring was installed and the remaining 6700 cycles were run without deterioration of the new seal.
- b. The power control module (including the servo valve tare flow) required an oil flow of .48 liters per minute (30 cubic inches per minute) at 827 kPa (120 psi) pressure to open the supply to 20 mm² in 0.072 seconds. Because the total supply stroke has considerable over travel, 0.25 seconds were required for the spool to travel the full supply stroke.
- c. Assuming a 50% efficiency in converting shaft power to hydraulic power, the .48 liter per minute flow at 827 kPa pressure represents a fuel economy penalty of approximately 0.02 MPG (gasoline).
- d. In general, the control module with the associated electronics operated smoothly and the spool position was repeatable within 0.1 mm (.004 inches).
- e. The original valve spool resulted in an excessive dead band between the supply and pump-off mode. The spool drawing (NASA 760722) has been changed to reflect a smaller dead band.

Power Control - Sub-task 08 (Continued)

The computer program initially written to determine the mechanical losses of the hydrogen compressor has been expanded to enable the additional calculation of pumping work. The program has the capability of determining sliding seal friction and the resultant shaft power.

The Compressor Test Rig experienced scuffing in both cylinder walls after 3 hours of initial steady running. The cylinder walls were rebored, the plunger-posts were realigned, and testing was resumed.

The initial analytical study of compressor losses and their impact on fuel economy has been completed. Figure II-7 is a tabulated summary of this study, indicating a fuel economy opportunity of 0.56 MPG (gasoline) with an external compressor. The study also indicates that a fuel economy opportunity of 0.62 MPG (gasoline) may be realized by short circuiting the internal compressors in the 4-215 engine. However, engine tests with short circuited compressors have indicated 0.32 MPG opportunity. This discrepancy is attributed to initial compressor flow losses that are not considered in the analytical model.

FUEL ECONOMY ASSESSMENT

The assessed maximum fuel economy improvement opportunity of Power Control, sub-task 08, was decreased in May, 1978 from 1.44 MPG to 1.39 MPG (gasoline). This decrease was due to a reassessment of the Sealed Dome sub-sub-task. It was decided that this sub-sub-task would be reduced from 0.05 MPG to 0.00 MPG. However, in June, 1978 the fuel economy opportunity of Power Control was increased from 1.39 MPG to 1.40 MPG (gasoline). This increase was the result of a better hydrogen compressor loss analysis.

SYNOPSIS OF ENGINEERING NOTE PEN-159

"Hybrid Power Control"

Objective:

Determine a preliminary estimate of control dead volume and compressor capacity for a hybrid power control in the 4-215 Stirling engine.

Summary:

This engineering note considers the incorporation of dead volume as a control variable in the 4-215 Stirling engine, together with the current mean pressure control.

Results:

The optimum control dead volume (CDV) was determined to be 308 cc/cycle with a 0.76 MPG M-H fuel economy improvement. Although the maximum fuel economy improvement occurred at a CDV of 651 cc/cycle, the additional 343 cc accounted for only an additional 0.18 MPG improvement or a total fuel economy improvement of 0.94 MPG. However, using a CDV of 651 cc would require a larger compressor if engine short circuiting was to be avoided during power reductions, and a larger compressor would present packaging problems, as would the additional dead volume. The compressor capacity and control dead volume requirements vs. fuel economy improvement relationship is shown in figure . The compressor requirements are shown for both solid and hollow pistons.

HYBRID POWER CONTROL

CONTROL DEAD VOLUME AND COMPRESSOR CAPACITY VS FUEL ECONOMY IMPROVEMENT

4-215 STIRLING ENGINE
4500 LB. IWC VEHICLE

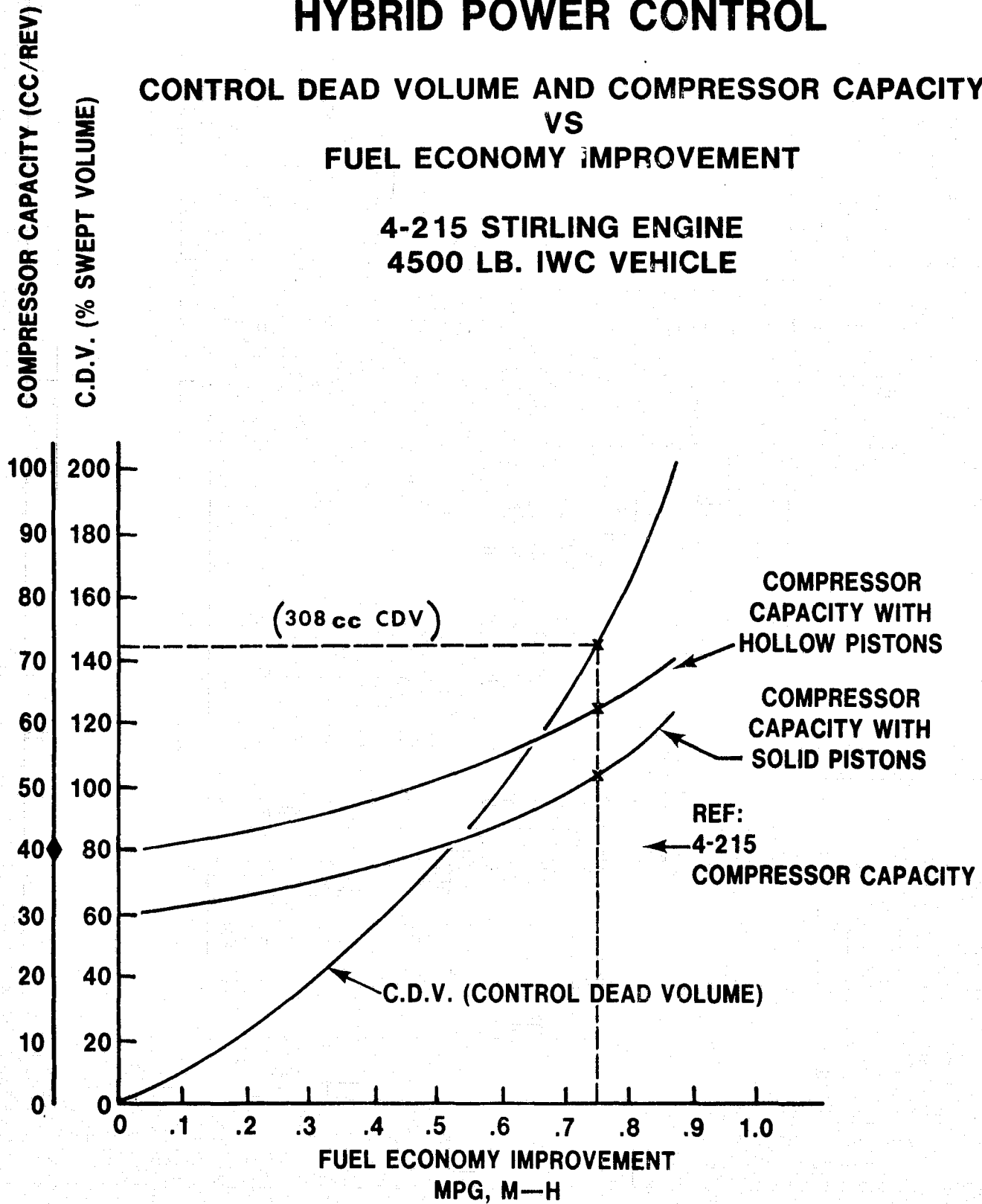


FIGURE -1

SYNOPSIS OF ENGINEERING NOTE PEN-160

"Dead Volume: Gas Flow Analysis"

Summary:

A computer program, "FCDVAREA", has been written which analyzes the flow conditions existing through the valve connecting a control dead volume element to the cycle portion of a Stirling engine using dead volume as a power control parameter.

A minimum valve area of 100 mm^2 is necessary for a control dead volume of 308 cm^3 in the 4-215 D.A. engine configuration.

Theory:

At the beginning of each calculation increment, both the pressure difference across the valve and the mean cycle pressure are assumed known. Relationships are presented which determine instantaneous cycle pressure and amount of gas in the cycle. During each increment these equations are solved, new pressure levels established, and the entire procedure repeated until a steady state is achieved.

Indicated torque is calculated at the end of each iteration.

Results:

The output from "FCDVAREA" has been used to estimate the correct valve size required to connect the control dead volume element to the engine cycle.

Initial runs were made for severe engine conditions in order to maximize the possible effects of incorrect valve sizing. For large amounts of control dead volume a complete torque reversal may be effected by changing only the effective flow area.

The torque reduction is due to a phase shift of pressure variation relative to volume variation.

The next set of conditions analyzed by "FCDVAREA" were those presently considered to be representative for a dead volume/mean pressure hybrid power control system based on the 4-215 D.A. engine size and configuration, i.e.,

Control Dead Volume = 142% Swept Volume

Engine Speed = 1500 RPM

Initial Mean Pressure = 150 kg/cm^2

These conditions reflect the control concept of a dead volume element open to cycle variations only at low load points.

CONTROL DEAD VOLUME FOR HYBRID POWER CONTROL

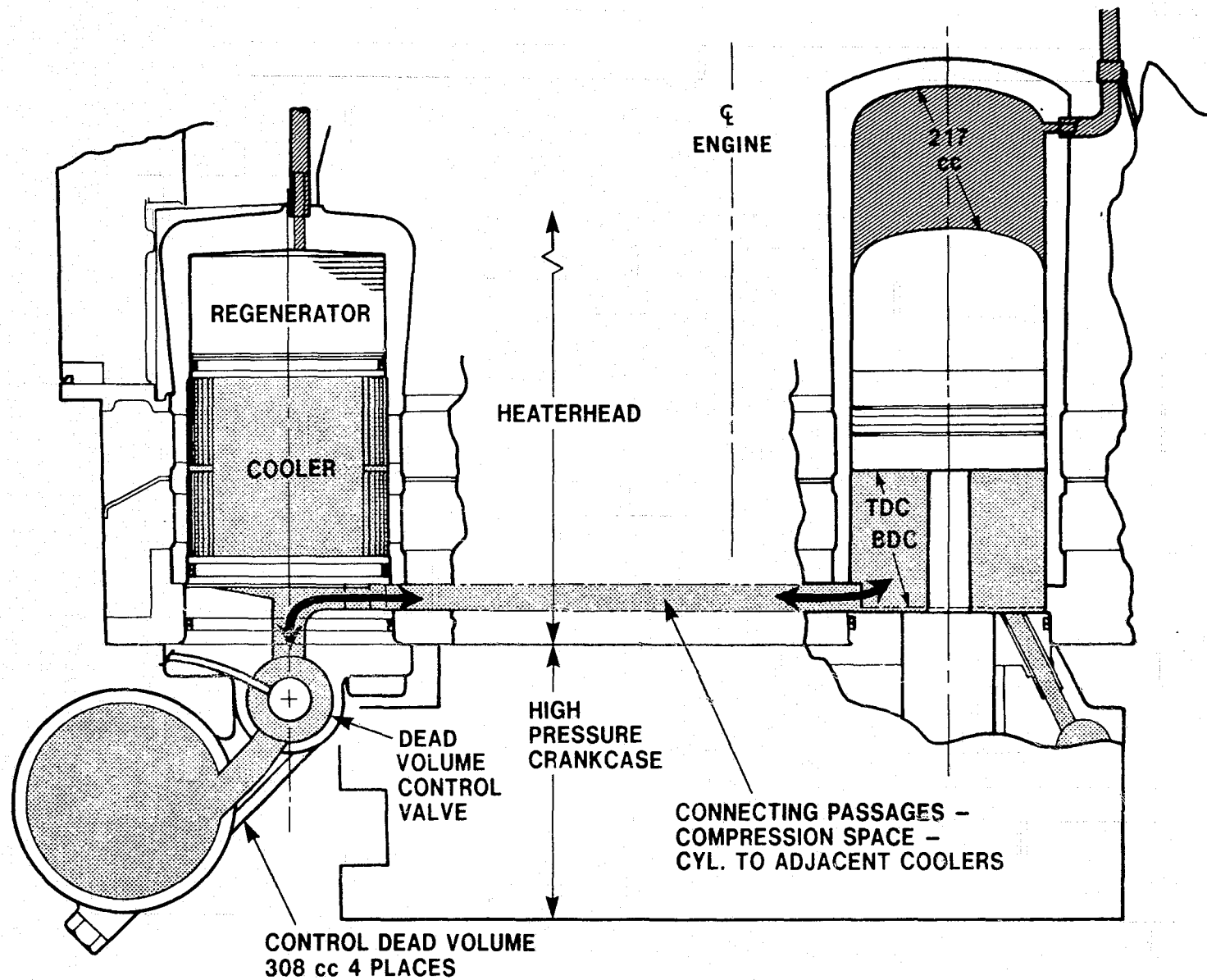
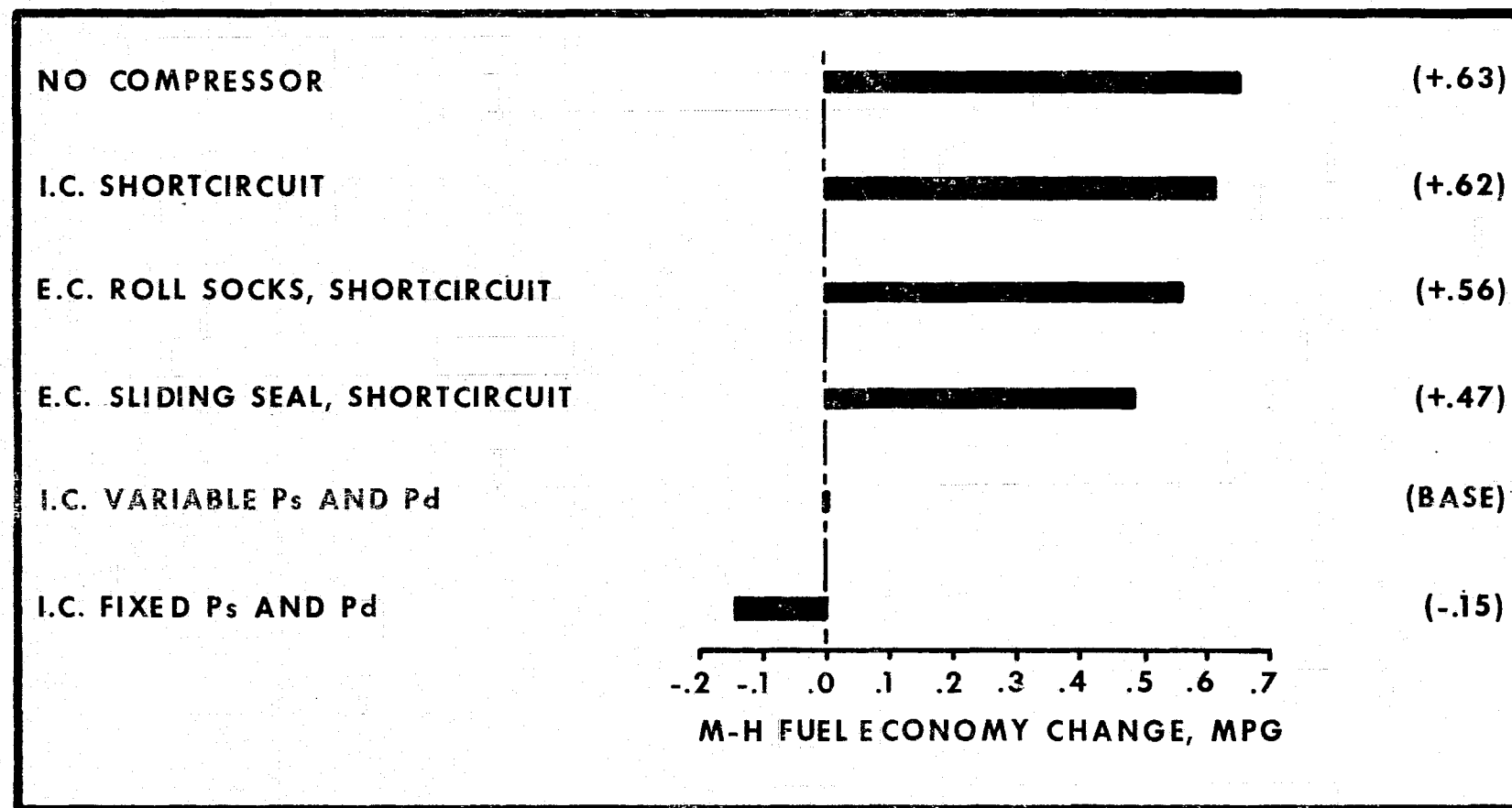


FIGURE II-6

FUEL ECONOMY EFFECTS OF POWER CONTROL COMPRESSORS AND COMPRESSOR OPERATING CONDITIONS

(COMPUTER SIMULATIONS)

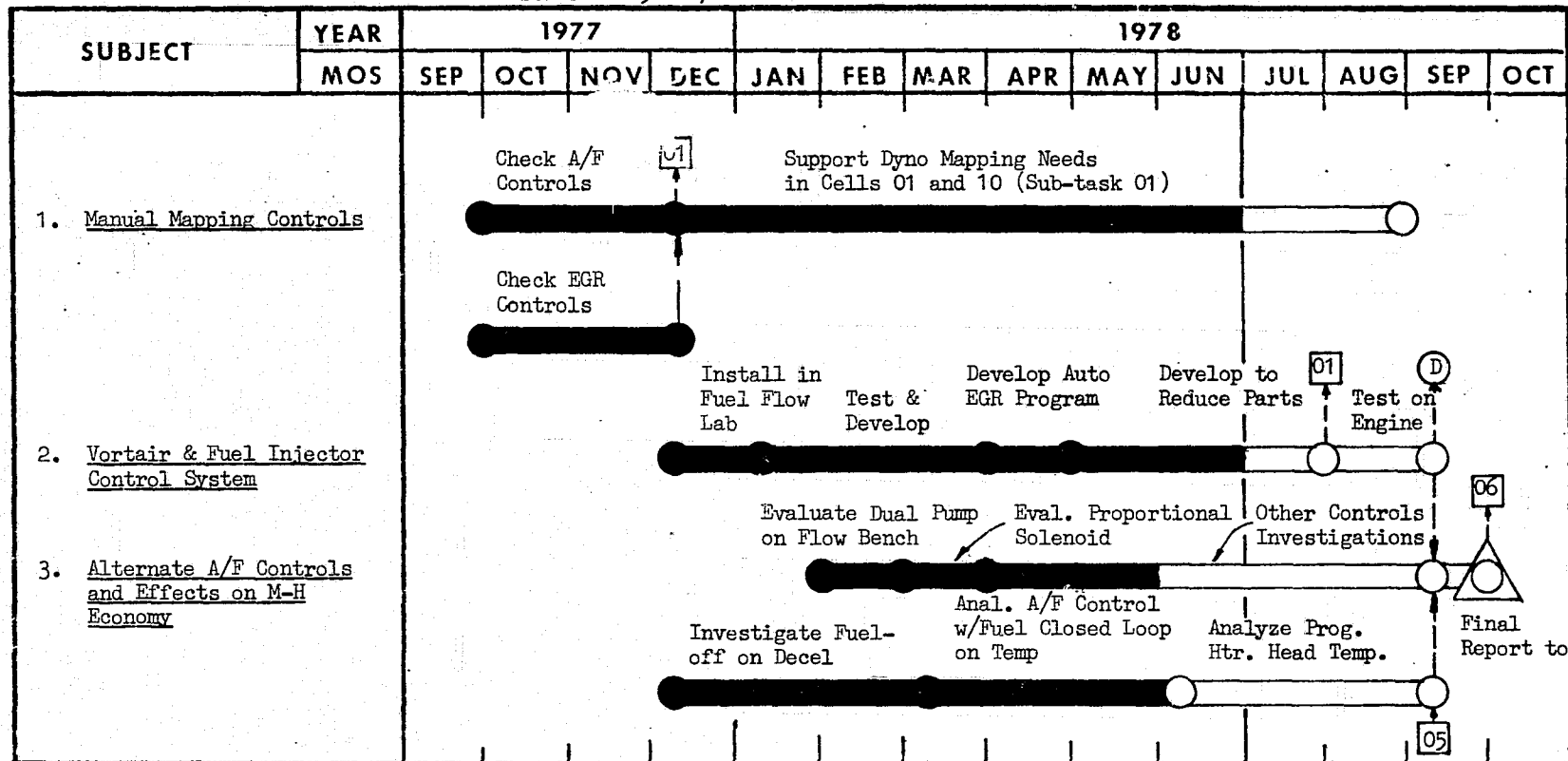


I.C. — INTERNAL COMPRESSOR (40cc/REV)

E.C. — EXTERNAL COMPRESSOR (53cc/REV)

P_s AND P_d — COMPRESSOR SUCTION AND DISCHARGE PRESSURES

SUB-TASK 09 AIR/FUEL CONTROL SYSTEM



Sub-Task No.	Sub-Task Description	ERDA Proposal Estimate (1)	(E) Estimate	(A) Theoretical Analysis	(C) Component Test	(D) Engine Test	Vehicle Projection
09	AIR/FUEL CONTROL SYSTEM (FENTON)	.2					.25
	.Low pressure drop A/F control	.04		.06			
	.Improve A/F control	.10	.10				
	.Reduce power loss of electronic power and control systems	-		.09		7/31/78	

AIR/FUEL CONTROL - SUB-TASK 09

Technical representatives from Ultra Electronics spent two weeks investigating a noise problem in the PAC 500 control. The problem was traced to a propagation delay that generated an erroneous pulse which introduced noise in the throttle valve drive circuitry. A circuit modification to the control eliminated the problem. The PAC 500 was then installed in cell 1.

The air/fuel control system in cell 10 was removed due to an apparent shift in calibration. This system was replaced with one from the fuel flow lab. Investigation revealed the shift in calibration was apparently due to slight circuit bias voltage shifts. The fuel control board circuit was modified to provide a stable reference voltage for the bias circuits.

The control and instrumentation systems in cell 1 have been checked-out by successfully controlling engine operations. A few problems were uncovered such as a defective integrated circuit in the fuel control board and a ground loop in the engine speed measuring circuit, but these problems were easily corrected. The PAC 500 programmable controller will allow rapid control loop changes during engine operation.

The wiring of the Engine Simulator Rig in cell 3 was completed and the air throttle and EGR valve positioning systems have been installed and checked out.

The test and evaluation of the United Stirling dual pump metering system has been completed. The varying frictional forces presented by the dual pump at low speeds, in the 0.4 grams/sec. fuel flow range, make it very difficult to provide a motor drive capable of holding a constant low RPM speed. It appears a special design motor and speed control would be required. An Engineering Note (PEN-169) of this evaluation was written and a synopsis is included (refer to Attachment 6). No further investigation of this metering system will be attempted during Task I.

A special readout device has been designed for use with the hydrogen pressure measurement instrument in cell 1. The instrument provides 0.05% accuracy measurement of engine hydrogen pressure.

Air/Fuel Control - Sub-task 09 (Continued)

Acoustic sensing Vortair air flow meters from J-TEK Corporation are being tested on the air flow rig to determine if they are candidates for use on the Stirling engine.

The test and evaluation of a turbine air flow meter from Autotronics Corporation has been completed and an Engineering Note (PEN-180) was written describing the results of those tests. A synopsis of that Engineering Note is attached (refer to Attachment 7).

FUEL ECONOMY ASSESSMENT

The assessed maximum fuel economy improvement opportunity of Air/Fuel Control, sub-task 09, remained unchanged at 0.25 MPG (gasoline).

SYNOPSIS OF ENGINEERING NOTE PEN-169

"USS Dual Pump Fuel Metering System"

Objective:

To evaluate the dual pump fuel metering system, supplied by United Stirling of Sweden, for use as a fuel metering device on the 4-215 Stirling engine.

Results:

The dual pump fuel metering system as supplied by United Stirling of Sweden is not acceptable for use with the Stirling engine air-fuel system. Test results show that due to the varying torque requirements at low speeds, a constant fuel flow cannot be obtained in the very low flow range with available drive motors and speed control schemes. The metering system must operate down to 0.4 grams/second to control at engine idle speeds. No further testing or investigation of this dual pump will be done during Task I.

Recommendations:

Providing a motor and speed control scheme to handle the varying torque requirements below .7 grams/second fuel flow would require significant development effort and time, therefore, the effort on the dual pump has been suspended for Task I.

SYNOPSIS OF ENGINEERING NOTE PEN-180

"Autotronic Air Flow Transducer"

Objective:

To investigate the turbine wheel air flow transducer, supplied by Autotronic Controls Corporation, for use as an air flow measuring device on the 4-215 Stirling engine.

Results:

The turbine wheel air flow measuring system as supplied by Autotronic Controls Corporation is not acceptable for use with the Stirling engine air/fuel system. Test results show a high pressure drop through this device. (See figure 1). The air flow measuring device must have a lower pressure drop than the N. V. Philips air restrictor, preferably as low as the Ford thermal Vortair units, throughout the operating range in order for the blower to provide the maximum air flow possible to the burner. No further testing or investigation of this air flow transducer will be done during Task I.

Recommendations:

Although the Autotronic air flow transducer possesses excellent linearity, repeatability, and good response characteristics throughout the operating range, its pressure drop is not compatible with the Stirling engine blower system. The effort on this air flow meter has been suspended for Task I.

INSERTION PRESSURE DROP FOR SEVERAL AIR FLOW SENSORS

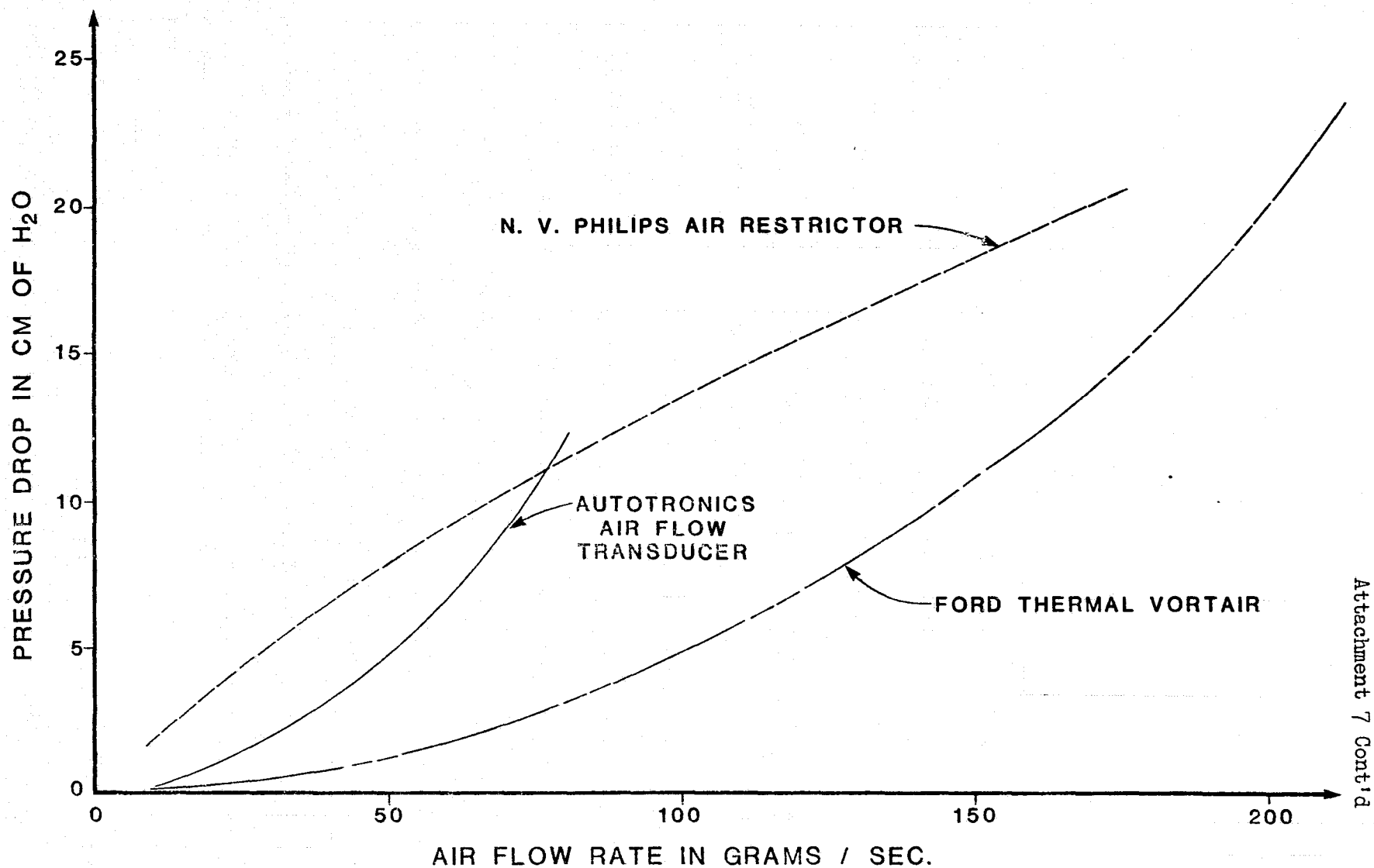
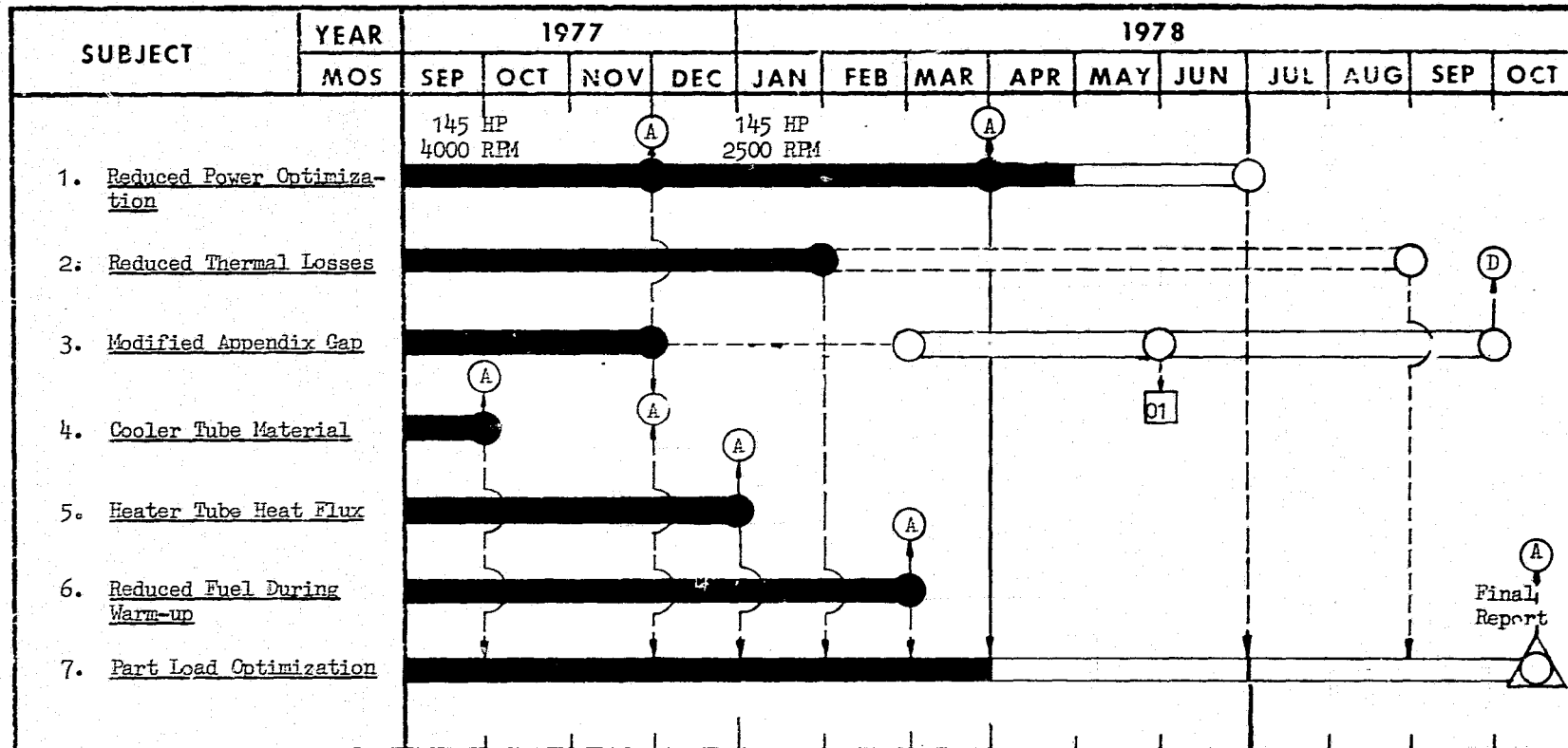


FIGURE 1

SUB-TASK 10 CYCLE ANALYSIS



FUEL ECONOMY ASSESSMENT (MPG)

Sub-Task No.	Sub-Task Description	ERDA Proposal Estimate (1)	(E) Estimate	(A) Theoretical Analysis	(C) Component Test	(D) Dyno. Engine Test	Vehicle Projection
10	CYCLE ANALYSIS (REAMS)	2.1					
	.Reduced power reoptimization	.63	-	3.84/70%			3.86
	.Reduced thermal losses	.16	-				
	.Modified appendix gap	.27	-				
	.H ₂ cooler tube material	.12	-				
	.Increased heater head heat flux	.16	.00				
	.Reduce fuel loss used for engine warm-up	-	.02				
	.Part load reoptimization	.63	-	*			

* Included in the 3.84 MPG estimate.

CYCLE ANALYSIS - SUB-TASK 10

The projected fuel economy improvement opportunity for sub-sub-task "Heater Tube Heat Flux" has been reduced from 0.16 MPG to 0.00 MPG. This is due to the fact that heater tube heat flux is primarily dependent on full-load power, engine length, and engine diameter. Once these factors and the geometric configuration of the engine are specified, an independent function of flux versus fuel economy cannot be determined. In addition, if flux levels much greater than those in the range of current Stirling engine experiences were projected, a detailed stress analysis would be required to have a sufficient confidence level for engine application.

An optimization was completed with the cold start fuel penalty incorporated into the optimized function. Analysis revealed that, using the same constraints and requirements of the fourth generation fuel economy engine on the 4-215 Stirling engine, there is no fuel economy improvement available. Therefore, the fuel economy improvement opportunity of sub-sub-task "Reduced Fuel During Warmup" has been reduced from 0.02 MPG to 0.00 MPG (gasoline).

An engine with the correct maximum power to meet the baseline performance level has been optimized. Work on finalizing the engine map for this fourth generation fuel economy assessment engine is under way.

Due to some problems in the optimization procedure (not the algorithm that calculates the Stirling cycle), previous optimizations were not searching properly for the maximum fuel economy. With these problems corrected, the results from the optimized engine indicate an increase in the incremental fuel economy improvement of 1.40 MPG (gasoline).

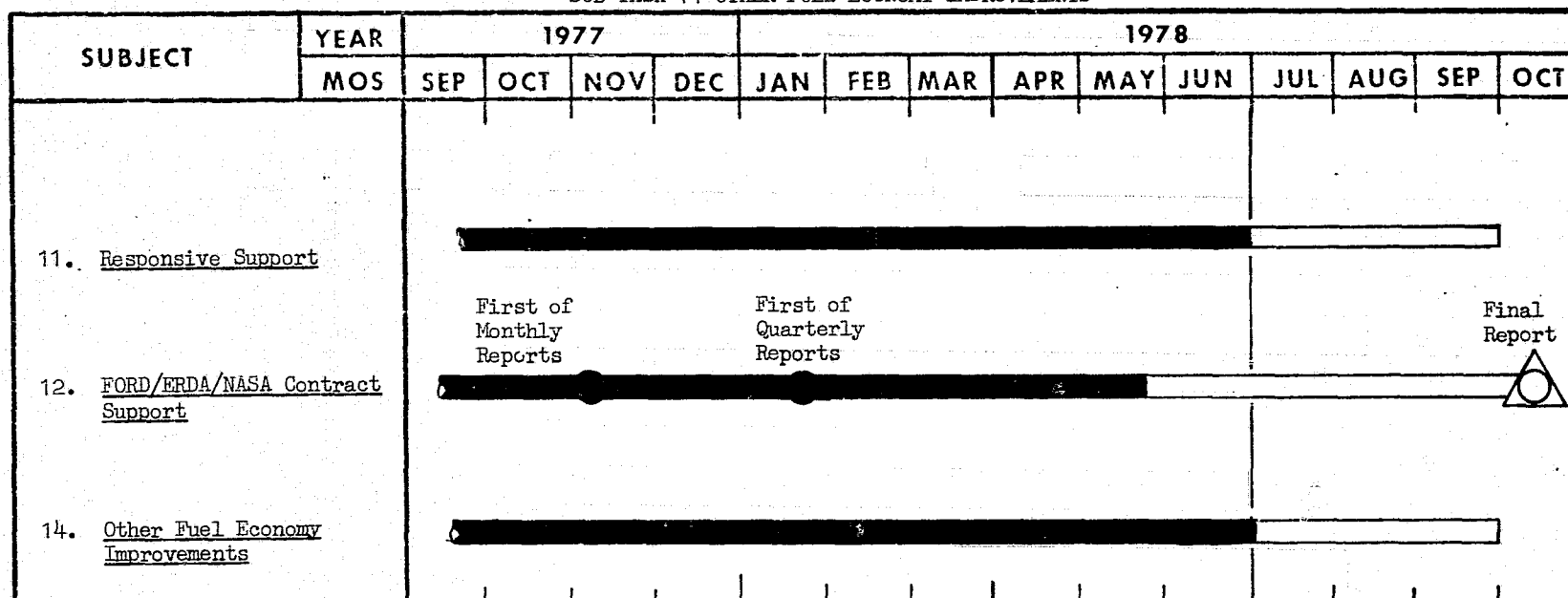
Work on a slow speed (2500 RPM) Stirling engine was discontinued because no fuel economy improvement opportunity was expected over the 4000 RPM engine.

Work was initiated to investigate a smaller Stirling engine with approximately the same performance as a 302 CID IC engine.

FUEL ECONOMY ASSESSMENT

The assessed maximum fuel economy improvement opportunity of Cycle Analysis, sub-task 10, was increased from 2.38 to 3.60 MPG (gasoline).

SUB-TASK 14 OTHER FUEL ECONOMY IMPROVEMENTS



Sub-task No.	Sub-Task Description	ERDA Proposal Estimate (1)	(E) Estimate	(A) Theoretical Analysis	(C) Component Test	(D) Dyno. Engine Test	Vehicle Projection
14	OTHER FUEL ECONOMY IMPROVEMENTS	-					2.52
	.Decreased air cleaner pressure drop	-	.02				
	.Accessory drive starting energy requirement	-	.02				
	.Reduction of engine & accessory inertia	-	.08				
	.Methods to reduce conduction losses (Insulation)	-	0.50				
	.Methods to reduce conduction losses (thin walls)	-		1.29/20%			
	.Fuel off during H ₂ overtemperature	-	+.61				

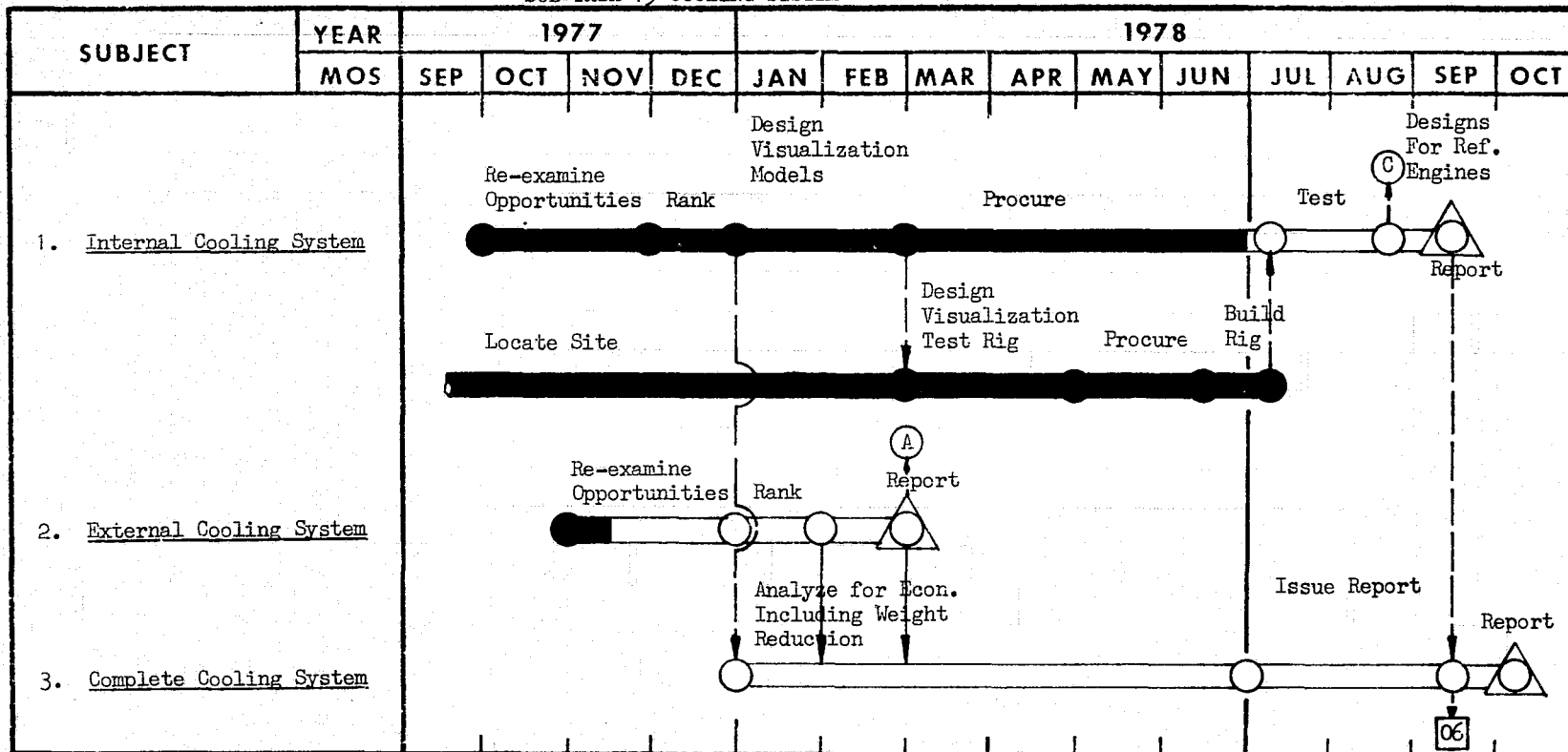
OTHER FUEL ECONOMY IMPROVEMENTS - SUB-TASK 14

Sub-sub task "Methods to Reduce Conduction Losses (Insulation)" has been added to this sub-task and the associated estimate for improvement in fuel economy of the fourth generation engine is 0.5 MPG (gasoline). This improvement estimate is based on the assumption that an insulating material may be installed in the engine which will decrease the conductive heat losses from the regenerator and cylinder walls to the engine coolant. It has been initially assumed that the insulating material will be 1/16" (1.588 mm) thick with a thermal conductivity of 0.090 BTU/hr-ft-°F (0.158 watts/m-°C).

FUEL ECONOMY ASSESSMENT

The assessed maximum fuel economy improvement contribution of Other Fuel Economy Improvements, sub-task 14, was increased from 2.02 MPG to 2.52 MPG (gasoline).

SUB-TASK 15 COOLING SYSTEM



Sub-Task No.	Sub-Task Description	ERDA Proposal Estimate (1)	(E) Estimate	(A) Theoretical Analysis	(C) Component Test	(D) Dyno. Engine Test	Vehicle Projection
15	COOLING SYSTEM (JONES)	.50					
	.Radiator fin improvement for lower pressure drop	-	.02				
	.W/P power reduction	-	.04				
							.06

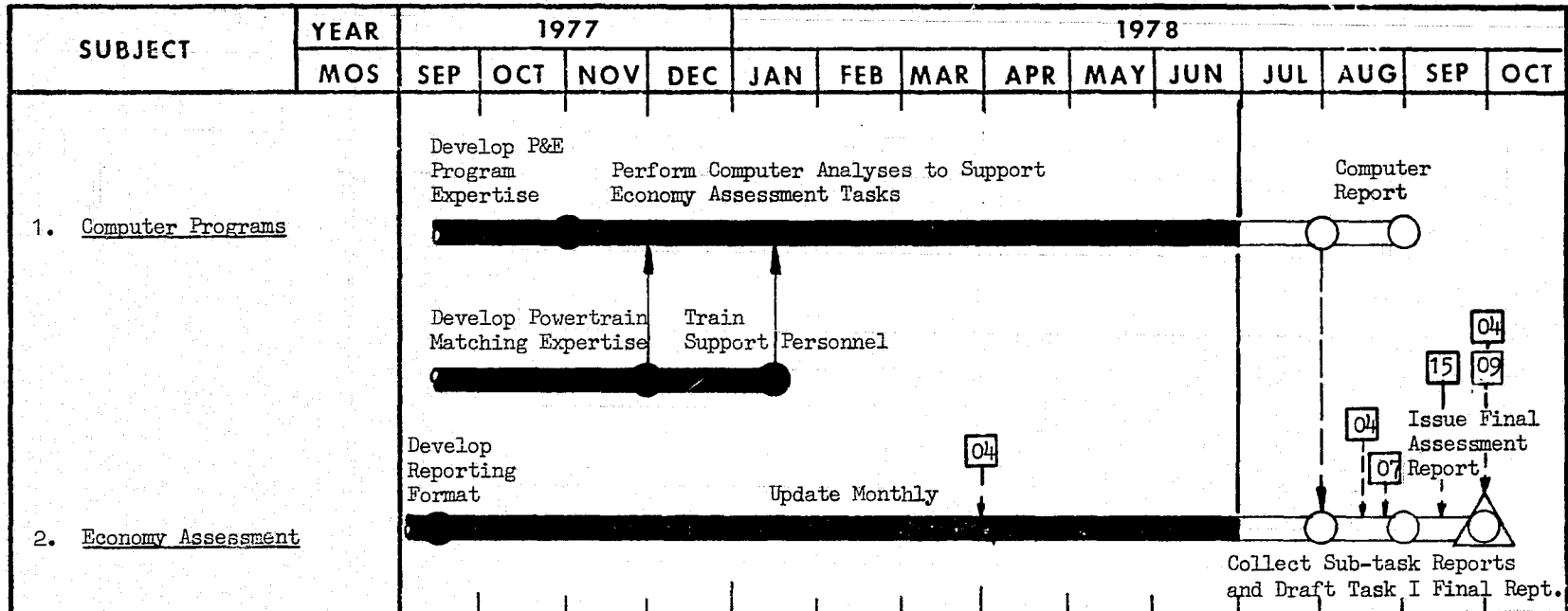
COOLING SYSTEM ANALYSIS - SUB-TASK 15

The transparent plastic model which simulates the Stirling engine water jacket in the vicinity of the piston rod seals was fabricated, inspected, checked for leakage, and delivered. This water jacket model will be evaluated simultaneously in a parallel flow configuration with the previously fabricated model of the 4-215 water jacket which simulates the area in the vicinity of the cylinder and regenerator-cooler housing walls. This evaluation will determine if modifications to the coolant distributions and local flow velocities to minimize flow resistance losses are required.

FUEL ECONOMY ASSESSMENT

The assessed maximum fuel economy improvement opportunity of Cooling System Analysis, sub-task 15, remained unchanged at 0.06 MPG (gasoline).

SUB-TASK 06 FUEL ECONOMY ANALYSIS



This Sub-task requires the complete Fuel Economy Assessment Chart (pages 1 through 5) which is attached.

FUEL ECONOMY ANALYSIS - SUB-TASK 06

The TOFEP computer program, which can be used to predict both fuel economy and performance, was modified as follows:

- a. The transmission shift points were changed to provide better part-throttle engine conditions. This modification has increased the accuracy of the predictions for engine operating conditions over the M-H driving cycle.
- b. The input data was modified to provide corresponding absolute fuel economy projections for the baseline vehicle when using the TOFEP and ECONCALC programs. Subsequent to these modifications, the greatest variation in projecting absolute M-H fuel economy of the baseline vehicle was 0.24 MPG (gasoline). Good agreement still exists between TOFEP and ECONCALC in predicting incremental fuel economy gains or losses associated with engine or vehicle changes.

2-65
The fourth generation engine map (TDEM247C) has a torque characteristic too low to achieve the 0-60 MPH acceleration time of the 351M IC engine-powered baseline vehicle, which is 13.3 seconds. Therefore, the PB1111 computer program was used to determine what changes were required to the torque levels of the TDEM247C engine map to achieve this performance time. Also, a new fourth generation Stirling engine map (preliminarily titled DKEM245) was generated using the latest engine optimization techniques. The shape of the torque curve of the DKEM245 engine map, to achieve a 13.3 second 0-60 MPH performance time, was determined using the PB1111 computer program.

Additional work was performed on powertrain optimization of the baseline vehicle equipped with the TDEM247C Stirling engine.

Two Engineering Notes (PEN-164 and PEN-165) were issued. PEN-164 details the results of performance calculations and computer simulation runs of M-H fuel economy for the baseline vehicle when equipped with the 4-215 and 4-247 Stirling engines and a 351M IC engine. PEN-165 describes torque levels required for the fourth generation Stirling engine to obtain a 0-60 MPH acceleration time of 13.3 seconds when installed in the baseline vehicle. A synopsis of these PEN notes is attached (refer to Attachments 8 and 9).

Fuel Economy Analysis - Sub-task 06 (Continued)

The Task I Fuel Economy Assessment Chart has been periodically updated to reflect changes in fuel economy projections that have occurred during each month of this reporting period. The latest changes for the month of June, 1978 include:

- a. In the Fuel Economy Assessment Chart Monthly Summary (Attachment 10) a new column titled "Confidence Weighted Opportunities" has been added. The number in this column represents the confidence-weighted fuel economy projection for the respective month. The confidence-weighted projection is determined by multiplying each maximum incremental fuel economy opportunity by its respective confidence level weighting factor. These numbers are totaled and added to the base fuel economy which is 13.9 MPG. (Fuel economy opportunities with confidence levels of 70% or greater are not weighted.)
- b. In the Task I Fuel Economy Assessment Chart (Attachment 11) the incremental fuel economy, which is listed in the "Vehicle Projection" column, was changed to include both minimum and maximum projections.
- c. Expected completion dates have been added to the open boxes in the "Component Test" and "Dynamometer Test" columns.
- d. Two baseline fuel economy projection numbers, 13.9 MPG and 15.7 MPG, now appear in the "Vehicle Projection" column on the summary page. These numbers represent the "best" estimate of current 4-215 capability (13.9) and the original 4-215 objective (15.7). The 13.9 MPG has been established on the basis of chassis dynamometer testing results of the 4-215 Stirling engine and will be used as the basis for fuel economy improvement projections.

SYNOPSIS OF ENGINEERING NOTE PEN-164

"Program Projection of Vehicle Fuel Economy and Performance"Introduction:

This note discusses the results of computer program simulation runs for metro-highway (M-H) fuel economy and performance projections of a 4500 lb. inertial weight class (IWC), 1977 LTD II vehicle when equipped with a 4-215 and 4-247 Stirling engine. For comparison purposes, computer simulation runs have also been made for fuel economy and performance of a 1977 LTD II equipped with a 351M internal combustion (IC) engine.

Values for fuel economies presented in this note are not intended to accurately reflect the absolute fuel economy potential of the Stirling engine.

Discussion:

A 1977 LTD II equipped with a 351M IC engine, automatic transmission, and a 2.50 rear axle ratio is defined as the baseline vehicle for the Stirling engine project.

The powertrain, road load, and weights of the baseline vehicle were used to obtain the computer program results presented in this report unless otherwise noted.

For the Stirling engines under evaluation, the cold start fuel penalty is calculated by estimating the heat value of the fuel and the mass of engine metal to be heated. For the 1977 351M internal combustion engine, the cold start fuel penalty was obtained from engine test data by taking the average difference in the city CVS-HOT and CVS-COLD-HOT fuel economy for ten (10) test runs with the same engine.

Results:1) Vehicle Performance

The 0-60 MPH WOT acceleration time, using TOFEP and PBL111, are listed in Table I.

Table I

Baseline Vehicle Projected 0-60 MPH Acceleration Time
Test Track Road Load Conditions

Engine Type	Projected 0-60 MPH Acceleration Time (Sec.)	
	PBL111	TOFEP
1977 351M	12.4	12.5
4-215 (Engine Map: TDEMBLVT)	11.4	11.4
4-247 (Engine Map: TDEM247C)	14.9	15.2

2) Vehicle Fuel Economy

For purposes of comparison, the fuel economies projected for the various engines, using the ECONCALC and TOFEP computer program, are presented in Table II as follows:

TABLE II

Baseline Vehicle Projected EPA Driving Cycle Fuel Economies (MPG)
Chassis Dynamometer Road Load Conditions ($Tr = 1.06$, PAU = 14.0 HP)*

	ECONCALC			TOFEP		
	City (HOT)	Highway	M-H	City (HOT)	Highway	M-H
351M	N/A	N/A	N/A	13.53	18.24	14.69
4-215 (Engine Map: TDEMBLVT)	15.15	20.36	16.05	14.53	20.93	15.81
4-247 (Engine Map: TDEM247C)	17.62	22.87	18.11	17.44	23.62	18.21

* Tr = Tire Rolling Resistance Coefficient

PAU = Chassis Dynamometer Power Absorber Unit

SYNOPSIS OF ENGINEERING NOTE PEN-165

"Torque Requirements for Fourth Generation Engine"Introduction:

PEN-161 describes the torque characteristics of the fourth generation Stirling engine that are required to maintain a baseline vehicle 0-60 MPH acceleration performance of approximately 13.3 seconds. At the time that PEN-161 was issued the TDEM247C engine map was the current engine map for the fourth generation Stirling engine. The torque requirements promulgated by PEN-161 were determined by applying linear scaling factors to increase the WOT torque, defined by the TDEM247C engine map wide open throttle "C" curve, in order to obtain the 13.3 second acceleration time objective.

Discussion:

The TDEM247C engine map has since been made obsolete by the latest computer program optimization for the fourth generation Stirling engine. This latest computer program optimization has produced a new fourth generation Stirling engine wide open throttle "C" curve that differs in shape from the TDEM247C engine map wide open throttle "C" curve. Accordingly, the engine torque curve band presented in PEN-161 is no longer applicable.

The new required torque characteristics, determined using the same rational as presented in PEN-161 of allowing a 0-60 MPH acceleration time of between 13.0 to 13.5 seconds, are presented as follows:

Engine Speed (RPM)	Engine Torque (ft-lbs) For 13.0 Sec. 0-60 MPH	Engine Torque (ft-lbs) For 13.5 Sec. 0-60 MPH
	<u>Acceleration-PB1111 Projected</u>	<u>Acceleration-PB1111 Projected</u>
600	322.0	312.0
1000	331.2	326.0
1500	333.7	322.5
2000	317.4	307.6
2500	292.6	283.5
3000	265.1	256.9
3500	232.5	225.3
4000	197.0	190.9
4500	156.4	151.6

The attached graph of engine torque vs. engine speed depicts the new fourth generation Stirling engine torque requirements as well as the torque vs. speed characteristics of the 1977 351M internal combustion engine. (See Figure 1.)

Vehicle 0-60 acceleration times may be altered by changing the first to second gear shift speed of the automatic transmission. With the TDEM247C engine map, increasing the first to second gear shift speed would result in lower 0-60 MPH acceleration times (improve performance). However, with the shape of the current fourth generation Stirling engine curve (preliminary map entitled DKEM245) it has been found that the optimum 0-60 MPH acceleration shift speed is the same as that specified for the baseline vehicle.

GRAPHS OF ENGINE NET TORQUE VS. ENGINE SPEED

Figure 1

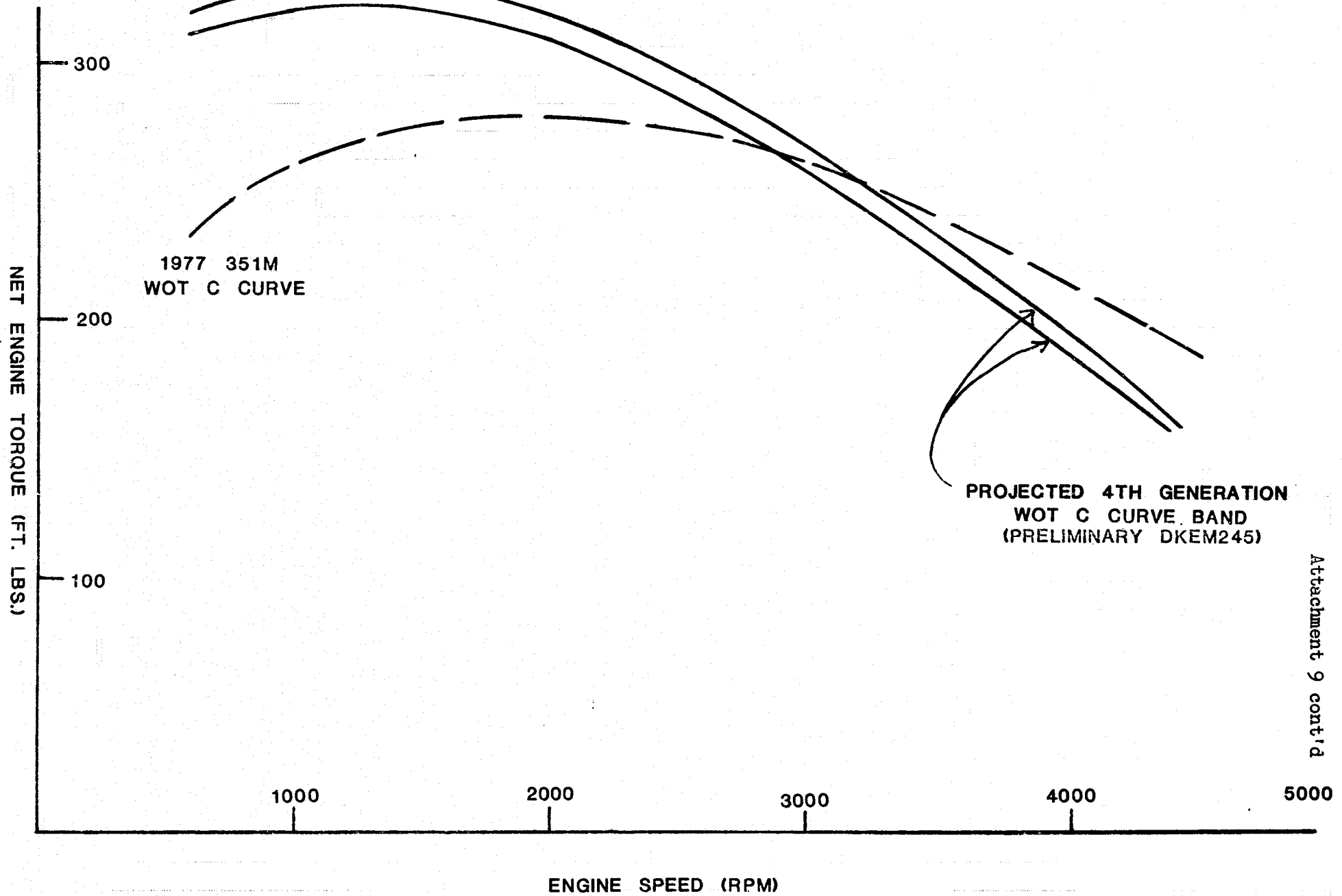


TABLE I

TASK IFUEL ECONOMY ASSESSMENT CHARTMONTHLY SUMMARY

<u>Date of Issue</u>	<u>Maximum Opportunity 4th Generation^{a/} Engine Projections (MPG)</u>	<u>Confidence Weighted Opportunities (MPG)^{c/}</u>	<u>Confidence Level (%)</u>	
			<u>Present</u>	<u>Expected</u>
July 1977	22.00	-	27%	-
Aug 1977	22.00	-	27%	52%
Sept 1977 ^{b/}	21.16	-	29%	54%
Oct 1977	21.16	-	29%	54%
Nov 1977	21.23	-	29%	54%
Dec 1977	22.11	-	29%	54%
Jan 1978	23.65	-	37%	54%
Feb 1978	23.68	-	37%	53%
March 1978	23.69	-	40%	55%
April 1978	23.69	-	40%	55%
May 1978	26.33	-	44%	54%
June 1978	26.12	19.6	44%	53%

^{a/} Phase I objective - 15.7 MPG
DOE Proposal Estimate - 20.6 MPG

^{b/} Start of contract

^{c/} Based on the 4-215 at 13.9 MPG

TASK I - FUEL ECONOMY ASSESSMENT

SUB-TASKS 01-15

INCREMENTAL IMPROVEMENT
IN METRO-HIGHWAY FUEL ECONOMY

Low

Confidence Level

High

Sub-Task No.	Sub-Task Description	ERDA Proposal Estimate (1)	Estimate (Min)-(Max)	Theoretical Analysis (Min)-(Max)	Component Test (Min)-(Max)	Dynamometer Engine Test (Min)-(Max)	Vehicle Projection (Min)-(Max)
01	MAPPING & OPTIMIZATION (ERVIN)	.4					.05 - .25
	. Reduced EGR reqmts	.04	.02-.04			7-31-78	
	. Reduced exh back pressure	.03	.01-.03				
	. Minimum air flow reqmts	.04	.02-.04				
	. Temperature scheduling	.27	.05-.15	0-.14/20%			
02	BURNER SYSTEM (REAMS)	.2					0 - .02
	. Low pressure drop burner	.02	0-.02		7-1-78	7-10-78	
	. Improved heater head temperature distribution	.13	.08-.18	0	7-1-78		
03	PREHEATER (REAMS)	.3					.37 - .44
	. Engine driven preheater	.14		.14-.16	7-15-78	7-10-78	
	. Thin wall material preheater core	.14		.23-.26/70			
	. Reduced preheater leakage	.02	0-.02		7-15-78		
	. Seal friction reduction	.01	0				

Low

Confidence Level

High

Sub-Task No.	Sub-Task Description	ERDA Proposal Estimate (1)	Estimate (Min)-(Max)	Theoretical Analysis (Min)-(Max)	Component Test (Min)-(Max)	Dynamometer Engine Test (Min)-(Max)	Vehicle Projection (Min)-(Max)
04	ENGINE DRIVE SYSTEM (KANTZ)	.2					0.95 - 1.69
	. Crankshaft vs swashplate	.10		.55-1.10			
	. Accessory drive	.05	0-.08	9-1-78			
	. Engine drive for fuel & atomizing air pump	-		.22-.27	7-1-78		
	. Piston ring friction	-					
				.18-.24	7-1-78	8-1-78	
05	EXTERNAL HEAT AND BLOWER SYSTEM (KANTZ)	.1					.26 - .46
	. Improved blower design	.04		.05-.11	9-1-78		
	. Improved blower drive	.05	0-.08	9-1-78			
	. Reduced air flow reqmts. (ref. Sub-task 10)	-		.21-.27	9-1-78		
08	POWER CONTROL SYSTEM (KOSACHEFF)	.9					.89 - 1.39
	. Alternate power control	-		.54-.74			
	. Reduce power losses of power control actuator needed for fast transient response	-			0-.02		
	. Hydrogen compressor losses	.85		.35-.55	8-30-78	7-30-78	
	. Eliminate "short circuiting" power losses during decelerations	-		0-.03			
	. Hydrogen distributor friction	.05	0-.05	8-31-78			
	. Sealed piston dome	.05(2)		0			

High

Sub-Task No.	Sub-Task Description	ERDA Proposal Estimate (1)	Estimate (Min)-(Max)	Theoretical Analysis (Min)-(Max)	Component Test (Min)-(Max)	Dynamometer Engine Test (Min)-(Max)	Vehicle Projection (Min)-(Max)
09	AIR/FUEL CONTROL SYSTEM (FENTON)	.2					0 - .25
	. Low pressure drop A/F control	.04		0-.06			
	. Improved A/F control	.10	0-.10			7-31-78	
	. Reduce power loss of electronic power & control systems	-		0-.09			
10	CYCLE ANALYSIS (REAMS)	2.1					3.01 - 3.34
	. Reduced power re-optimization	.63					
	. Reduced thermal losses	.16					
	. Modified appendix gap	.27		3.01-3.34/70%			
	. H ₂ cooler tube material	.12					
	. Part load reoptimization	.63					
	. Reduce fuel loss used for engine warm-up	-	-0-.02-	0			
	. Increased heater head heat flux	.16	0				

Low

Confidence Level

High

Sub-Task No.	Sub-Task Description	ERDA Proposal Estimate (1)	Estimate (Min)-(Max)	Theoretical Analysis (Min)-(Max)	Component Test (Min)-(Max)	Dynamometer Engine Test (Min)-(Max)	Vehicle Projection (Min)-(Max)
14	OTHER FUEL ECONOMY IMPROVEMENTS	-					.50 - 2.52
	. Decreased air cleaner pressure drop	-	0-.02				
	. Accessory drive starting energy reqmts	-	0-.02				
	. Reduction of engine and accessory inertia	-	0-.08	8-1-78			
	. Methods to reduce conduction losses (thin walls)	-		.30-1.29/20%			
	. Fuel off during H ₂ overtemperature	-	0-.61				
	. Methods to reduce conduction losses (insulation)	-	.20-.50				
15	COOLING SYSTEM (JONES)	.50					0 - .06
	. Radiator fin improvement for lower pressure drop	-	0-.02	9-1-78			
	. W/P power reduction	-	0-.04		9-1-78		

Low

Confidence Level

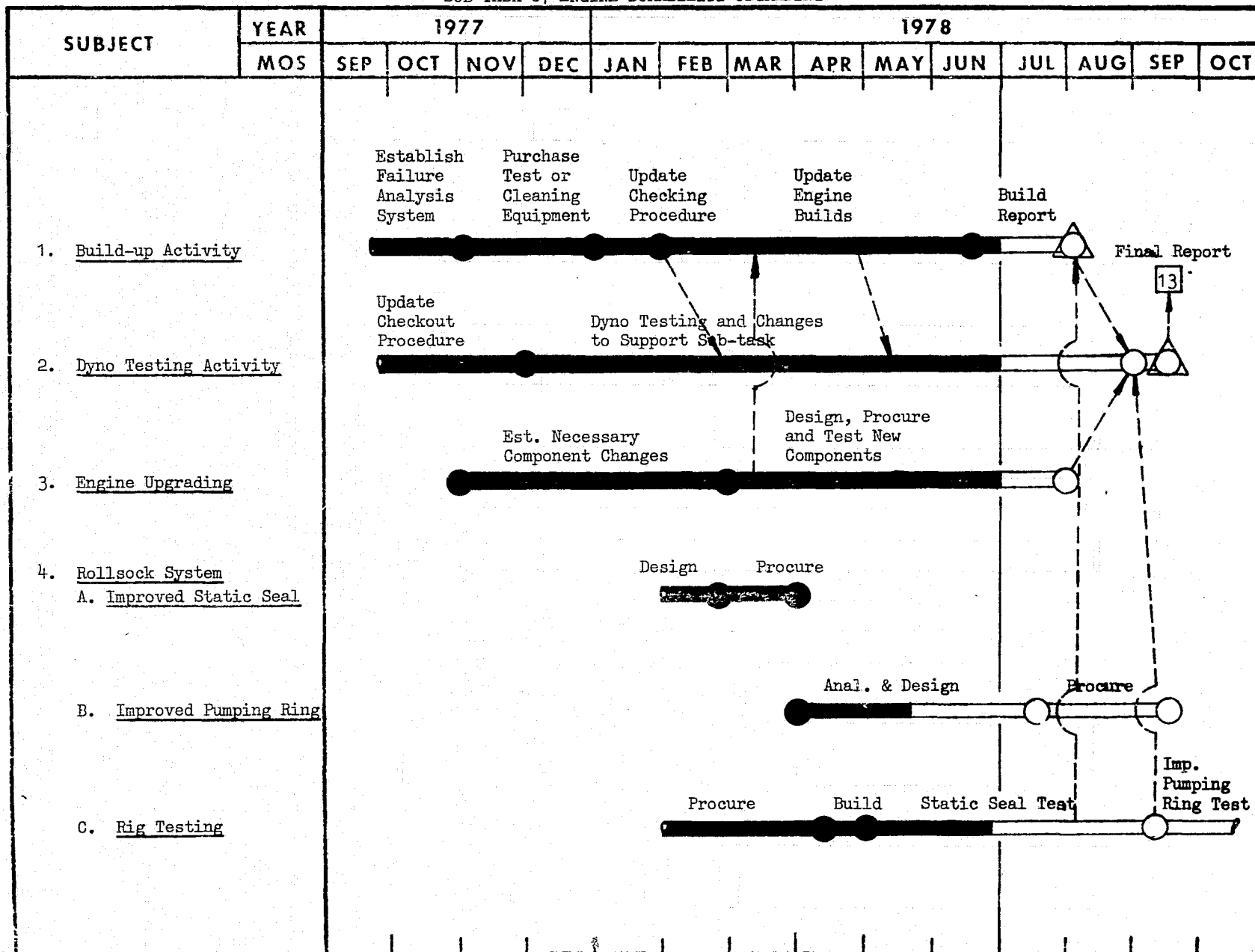
High

		Estimate (Min)-(Max)	Theoretical Analysis (Min)-(Max)	Component Test (Min)-(Max)	Dynamometer Engine Test (Min)-(Max)	Vehicle Projection (Min)-(Max)
PHASE I OBJECTIVES (3)	-	-	-	-	-	13.9 - 15.7
ERDA PROPOSAL ESTIMATE (1)	4.90	-	-	-	-	20.6
FOURTH GENERATION ENGINE TECHNOLOGY (4)	-	.25-1.75	5.78-8.65	0-.02	0	19.93 - 26.12 ^{6/}
Confidence Level Weighting Factor		.20	.40	.60	.80	
Confidence Level of ⁽⁵⁾ Present Projections		44% to meet 26.1 MPG 57% to meet 20.6 MPG				
Expected Confidence ⁽⁵⁾ Level		53% to meet 26.1 MPG 72% to meet 20.6 MPG				

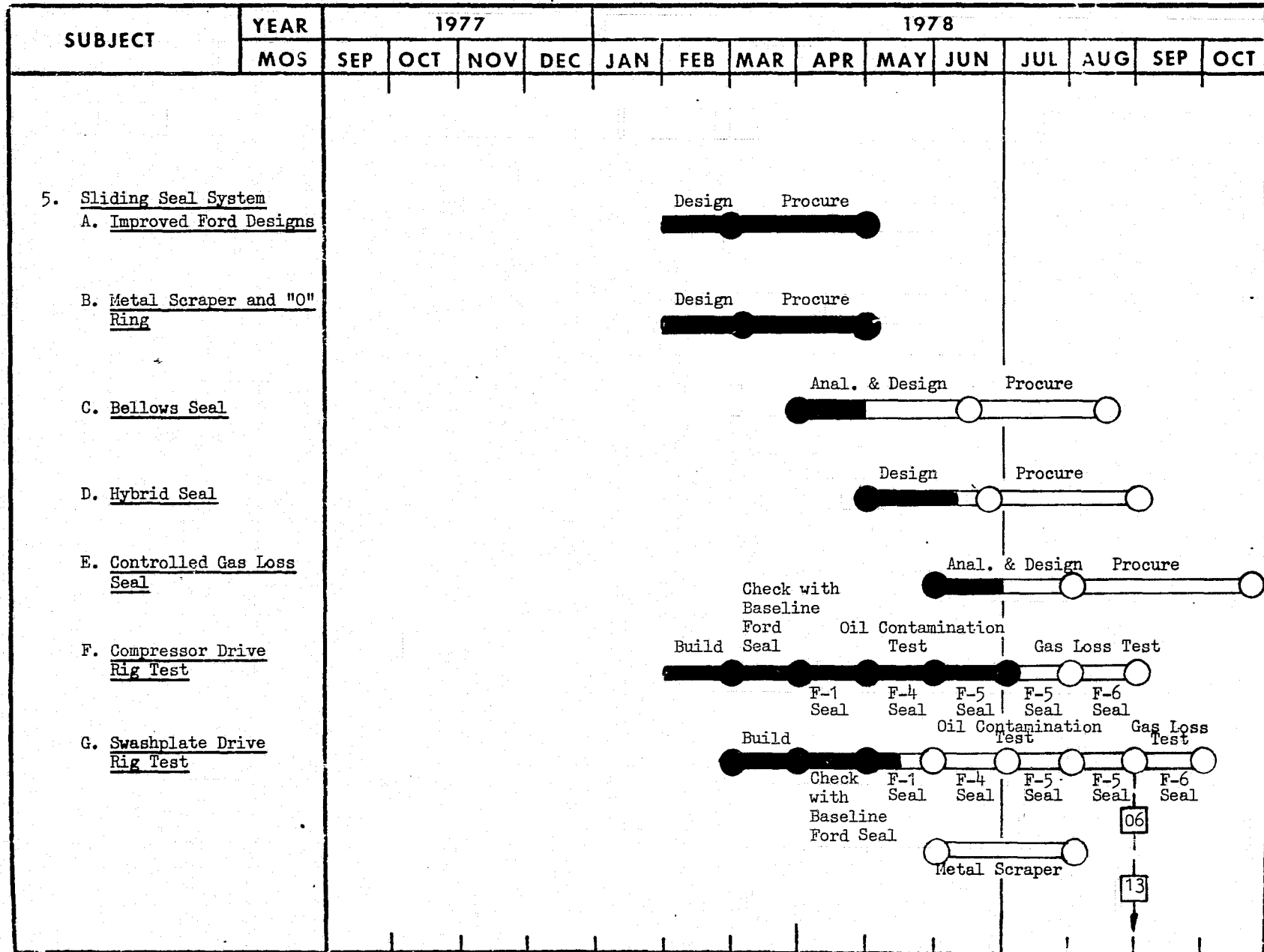
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- (1) ERDA Proposal May 12, 1977 Volume II, Exhibit VII, page 5
- (2) Estimate included in the Total of CYCLE ANALYSIS, No. 10
- (3) Phase I objective; 4500 lb. (IWC), 2.75 rear axle ratio, 12.7 sec. (0-60 time)
- (4) 1977 baseline vehicle; 4500 lb. (IWC), 2.50 rear axle ratio, 13.3 sec. (0-60 time)
- (5) Confidence level based on upper limit (Maximum) incremental M-H fuel economy improvements
- (6) Maximum opportunity based on 13.9 capability is estimated to be 24.32 MPG (M-H). The confidence weighted opportunity is 19.6 MPG (M-H).

SUB-TASK 07 ENGINE DURABILITY UPGRADING



SUB-TASK 07 ENGINE DURABILITY UPGRADING



ENGINE DURABILITY UPGRADING - SUB-TASK 07

Pressure drops were recorded on ten regenerators which were received from N. V. Philips. The data from the testing of these regenerators was transmitted to N. V. Philips for a theoretical analysis.

The Rollsock Seal Test Rig set-up was completed and testing was initiated on seal assemblies which were modified to include a check valve seal between the pumping ring and the rollsock. The purpose of this seal is to provide improved oil sealing during engine shut down. During engine running, the high pressure oil from the pumping rings will lift the check valve off its seat and flow past it to support the rollsock. During engine shut down, the pressure will reverse and force the seal ring between its seat and the shaft, thus establishing a static seal.

Two sets of F-1 seals were run on the Compressor Drive Test Rig. Each set allowed large amounts of oil into the gas space in a relatively short time. It has been determined that the oil was getting past the scraper. The scraper, Parker type D-562, is designed for a .562 in. (14.3 mm) diameter rod. Parker's Technical Services Department stated that this scraper would work on the 15 mm rod presently used in testing. Investigation of the scrapers removed from the first set of seals revealed that there was inadequate clearance between the 15 mm rod and the scraper behind the scraper lid. This was preventing the lip from contacting the rod properly.

Parts for the F-4 seals were delayed in shipping, so a Simrit oil scraper was installed in each F-1 seal cartridge and the oil contamination test was repeated. The scrapers are similar to those used by United Stirling of Sweden and are designed for use on 15 mm rods. The seals completed 100 hours of testing at 1000 RPM and 1100 psi mean pressure with no evidence of oil either in the cylinder gas space or inside the cartridge on the dry side of the scraper.

When the parts for the F-4 seals arrived, testing of a set of F-4 seal cartridges began on the Compressor Drive Test Rig. These seals use Parker "Polypak" seals as oil scrapers. The first set of cartridges completed approximately 65 hours of testing at 1000 RPM and 800 psi mean pressure with no indication of oil in the gas space. A temporary loss of cooling water caused the gas space temperature to increase to 240°F. The water supply was restored and the temperature was reduced to 160°F; however, within two hours a large quantity of oil was found in the gas space. Inspection revealed that both cap seals had failed and both Polypak scrapers had portions of their scraping edges melted. A second set of F-4 seals was installed in the rig and the test was repeated. One of the seals is using a solid ring instead of a cap seal to determine if the high wear and failure rates experienced

Engine Durability Upgrading - Sub-task 07

with cap seals can be avoided. This set has completed 87 hours at 1000 RPM and 850 psi mean pressure with no indication of oil in the gas space. The seal cartridge with the solid ring seal develops a maximum pressure 10% below that of the cartridge with the cap seal. This is probably caused by greater gas leakage past the slip ring seal. To date, this has had no noticeable effect on the performance of the seal.

The Swashplate Drive Test Rig modifications are complete and the reworked parts have been received. The following changes were made:

- a. The block holding the seal cartridges was welded for increased stiffness and to eliminate the gas leaks that developed during testing. The cartridge bores were also reground.
- b. The cylinder bores were reground to eliminate piston scuffing.
- c. Piston rings were added to the pistons to eliminate any pressure drop across the guide bushings. This will prevent excess friction on the guide bushings and will prevent the bushing from loosening.

Assembly of the rig is now complete.

International Packings Corporation, which is the United States distributor of "SIMRIT" seals, has been asked to quote on rod wipers similar to those used on the F-1 seals that will fit into the seal cartridge without modification.

The pumping rings failed to maintain pressure after 100 hours of running on the Rollsock Compressor Drive Test Rig. The rig was disassembled and the components are being checked.

The second pair of F-4 seals completed 100 hours of testing on the Compressor Drive Test Rig at 1000 RPM and 800 psi mean pressure. One seal assembly allowed no oil past the scraper either into the test cylinder or the seal cartridge. The other seal had a light film of oil inside the seal cartridge and possibly in the test cylinder. These seal assemblies differ in that one contained a piston ring type seal and the other contained a Philips cap seal.

A third pair of F-4 seals also completed 100 hours of testing on the Compressor Drive Test Rig at 1000 RPM and 1000 psi mean pressure. Both seal assemblies were equipped with a Parker SCL seal. One of the SCL seals failed after 50 hours of testing and was replaced with a solid ring made of Rulon LD. At the end of the test, the

Engine Durability Upgrading - Sub-task 07

cylinder with the solid ring had no oil in either the cartridge or the cylinder; however, the Rulon ring was badly worn and had extruded into the clearance gap. The other seal had a slight film of oil on the SCL seal only. None was found inside the cylinder or cartridge.

Testing of the fourth set of F-4 seals has been initiated on the Compressor Drive Test Rig. These seals have a Rulon LD scraper similar in design to the Philips white metal scraper.

Pressure switches were installed on the gas, oil, and cooling water lines of the Compressor Drive Test Rig. The rig is now running 24 hours/day.

Shakedown of the Swashplate Drive Test Rig revealed excessive power consumption. At 600 RPM, with a mean pressure of 700 psi, 220 ft-lbs of torque were required to drive the rig, and the gas temperatures were approximately 400°F. Some modifications were performed but affected the problem only slightly. Work on rectifying this problem will continue.

Two sets of Leningrader seal rings with pressure balancing grooves in two locations have been fabricated. These will be compared to standard Leningrader seals for friction vs gas pressure and gas leakage vs gas pressure.

It was determined that a bellows type oil seal is not feasible for Stirling engine application due to stroke, frequency, and fatigue-life requirement and geometric constraint.

An analysis was performed to determine the order of magnitude of the temperature gradient which exists along the piston rod, since a large gradient could possibly result in less effective sealing. Approximate modeling of the spatial heat generation, conduction, and rejection indicates that the expected temperature gradient is not acceptable. Measurement of the temperature along the rod will be attempted in the Sliding Seal Compressor Test Rig.

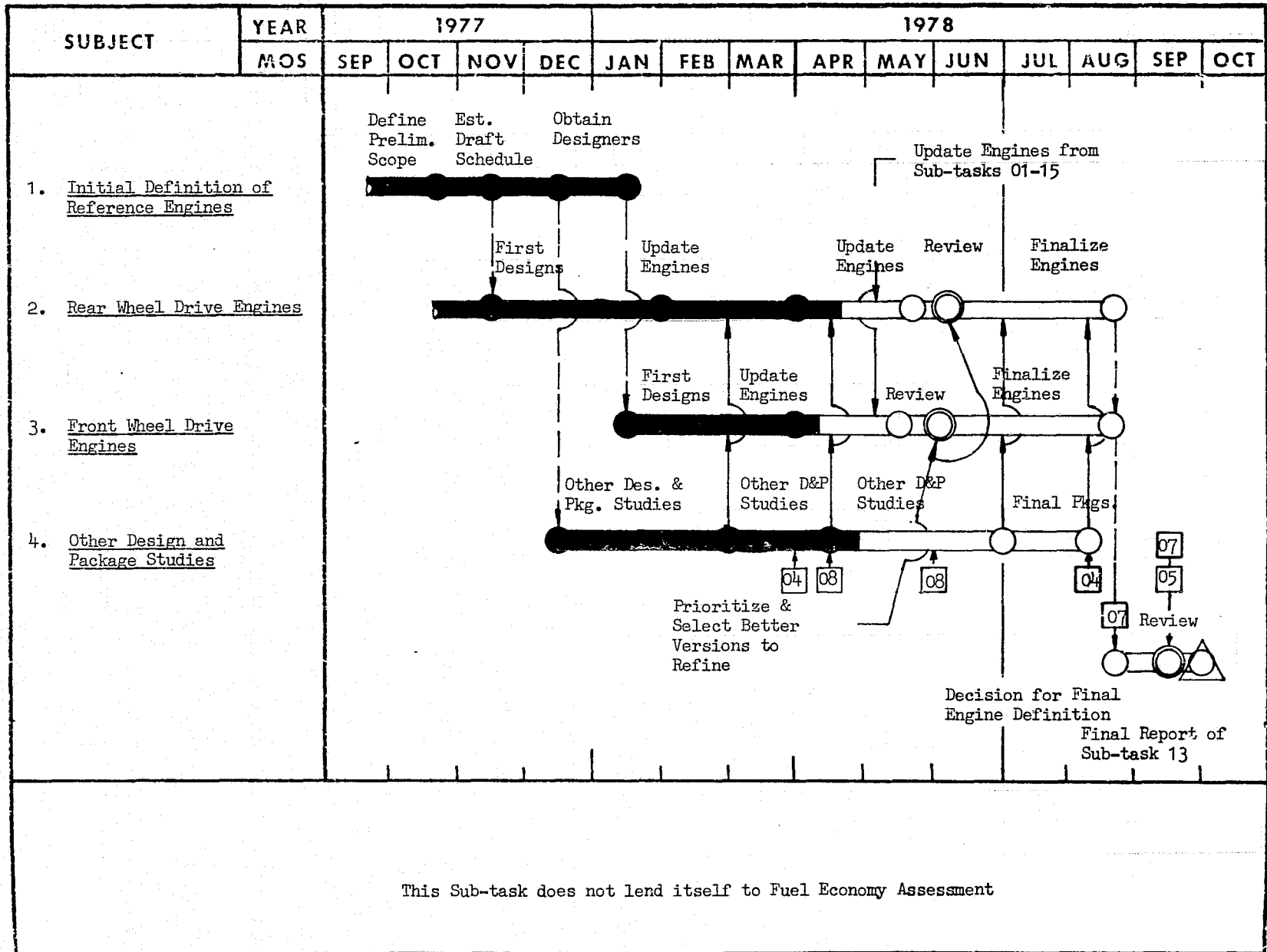
RESPONSIVE SUPPORT - SUB-TASK 11

No official presentations were given during this reporting period. Therefore, responsive support was not required.

CONTRACT SUPPORT - SUB-TASK 12

Three Monthly Technical Progress Narrative Reports were written and distributed during this reporting period.

SUB-TASK 13 REFERENCE ENGINE



This Sub-task does not lend itself to Fuel Economy Assessment

REFERENCE ENGINE - SUB-TASK 13

A more detailed version of a double crank engine is presently being laid out. Engine auxiliary mountings will be investigated in an effort to have more realistic engine installation studies.

A new swashplate engine layout was initiated which incorporates the following changes over the current 4-215 design.

- a. Crosshead modifications to reduce friction.
- b. A pin connection between the rod and crosshead to eliminate bending moments in the rod.
- c. Thinner swashplate.
- d. Shorter engine (3 inches).

END

DATE

JAN 11 - 1979